IAE Contribution for 3rd AIAA CFD High Lift Prediction Workshop (HiLiftPW-3)

Instituto de Aeronáutica e Espaço

021

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3rd AIAA CFD High Lift Prediction Workshop
Denver, CO June 3-4, 2017

Outline

- Summary of Cases Completed
- Code Summary
- Case 1a
- Cases 2a and 2c
- Concluding Remarks

Summary of cases completed: BRU3D, d-HLCRM_UnstrMixed_ANSA,, E-JSM_UnstrMixed_ANSA V1, Standard Spalart-Allmaras Turbulence Model (Note 1 (c)).

Case	Alpha=8, Fully turb, grid study	Alpha=16, Fully turb, grid study	Other
1a (full gap)	yes	yes	
1b (full gap w adaption)	no	no	
1c (partial seal)	no	no	
1d (partial seal w adaption)	no	no	
Other			

Case	Polar, Fully turb	Polar, specified transition	Polar, w transition prediction	Other
2a (no nacelle)	yes	no	no	
2b (no nacelle w adaption)	no	no	no	
2c (with nacelle)	yes	no	no	
2d (with nacelle w adaption)	no	no	no	
Other				

Case	2D Verification study	Other
3	yes	
Other		

Code Summary - BRU3D

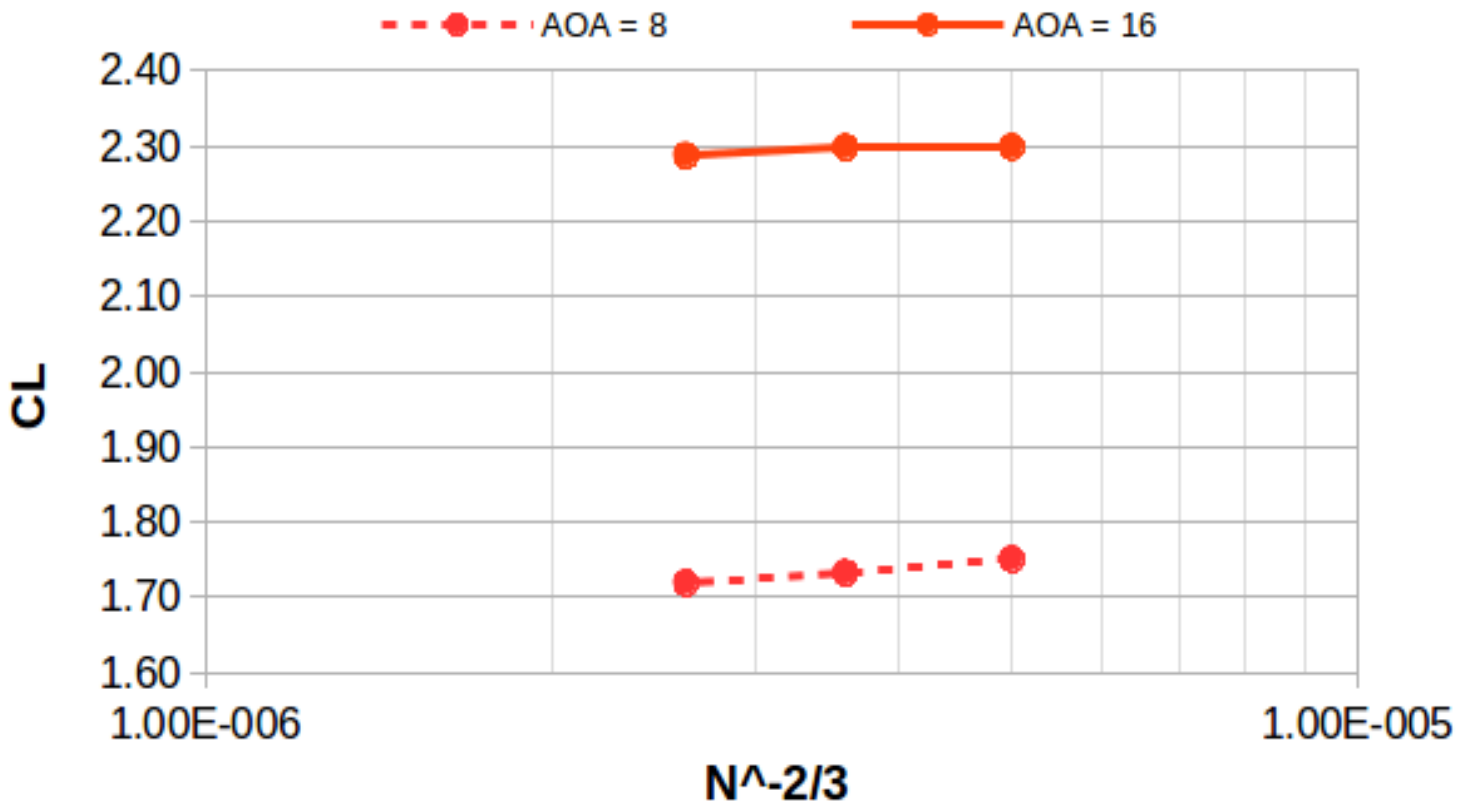
- 3-D compressible Reynolds-averaged Navier-Stokes (RANS) equations.
  - The flow is assumed to be fully turbulent.
- Standard Spalart-Allmaras turbulence model (Note 1c).
  - One equation model.
  - Linear eddy-viscosity assumption.
- Unstructured grid finite volume code.
- Second order accuracy in space.
  - Roe flux-difference splitting method.
  - To achieve second order accuracy in space, primitive properties are linearly reconstructed at volume faces with a MUSCL scheme.
  - Venkatakrishnan limiter.
- 1st-order backward Euler point-implicit scheme is used to march the solution.

Case 1a: Full Chord Flap Gap

- Case 1a - HL-CRM Grid Convergence Study, full chord flap gap.
  - MAC = 275.8 in
  - Wing semi-span = 1156.75 in
  - Sref/2 = 297,360.0 in^2
  - MRC : x=1325.90 in, y=468.75 in, z=177.95 in
  - Mach = 0.20
  - Re = 3.26 million
  - AOA's = 8 and 16 deg
  - Mesh : d-HLCRM_UnstrMixed_ANSA

Case 1a: Full Chord Flap Gap

- Lift vs. grid point no.

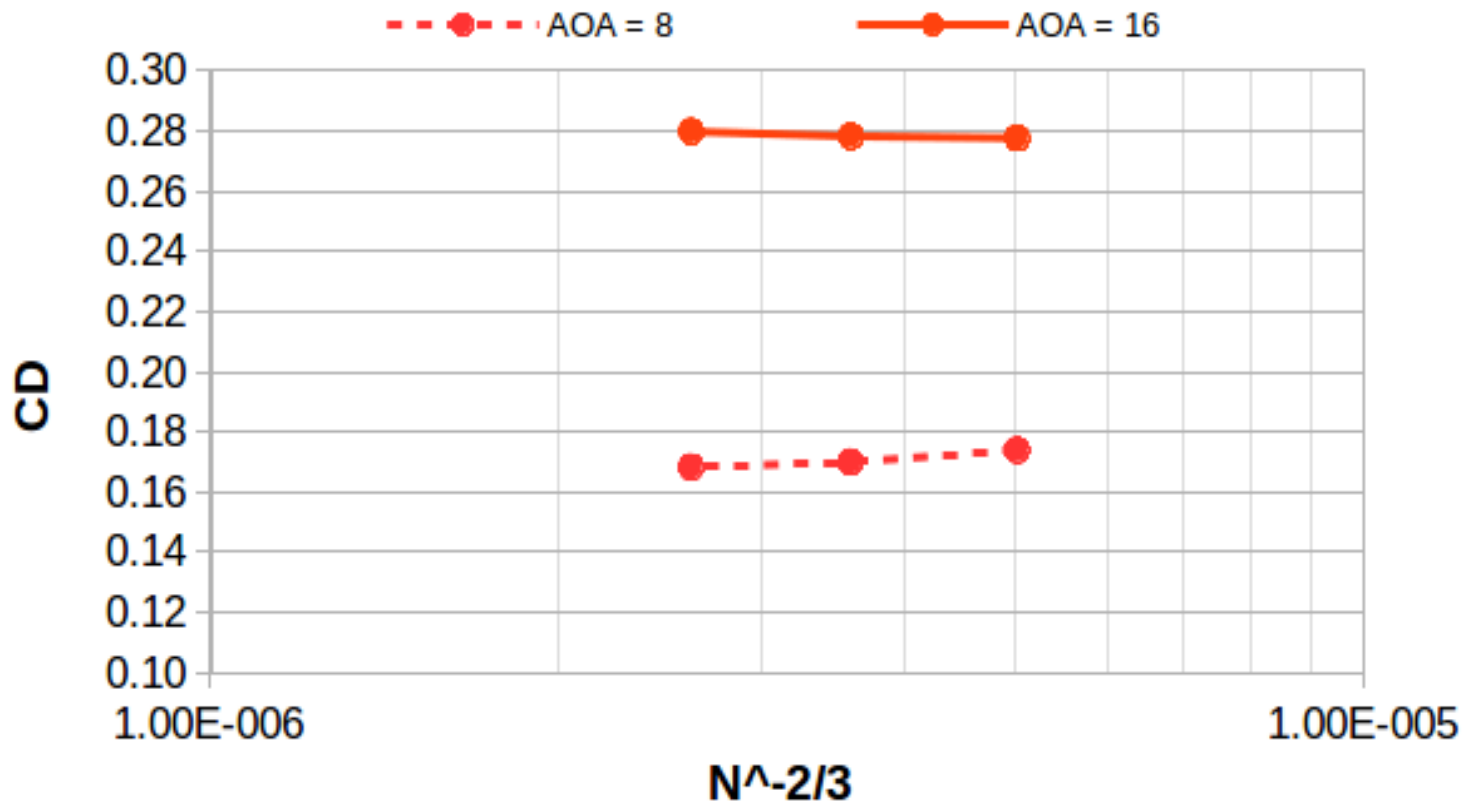


Case 1a: Full Chord Flap Gap

- Lift vs. grid point no.

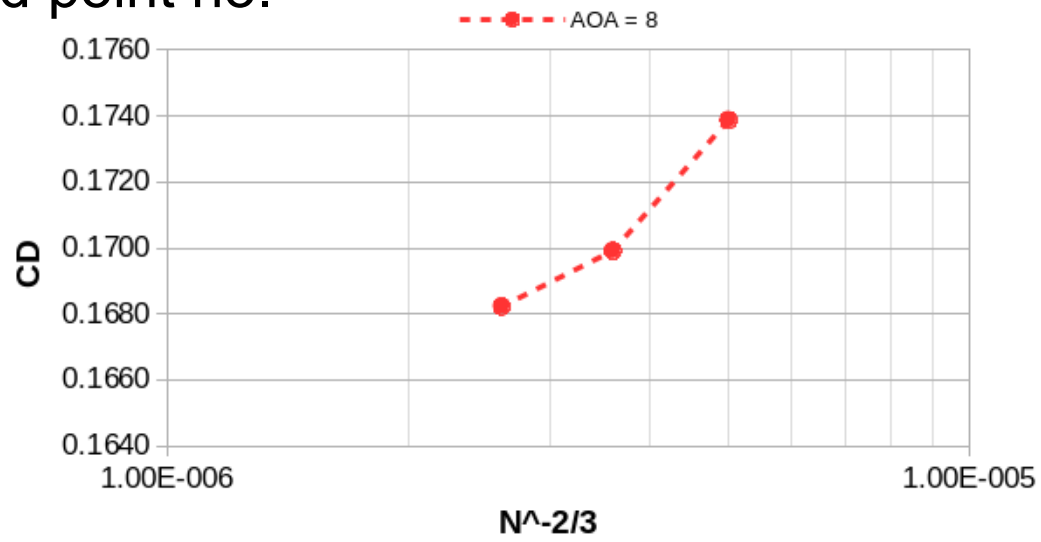
Case 1a: Full Chord Flap Gap

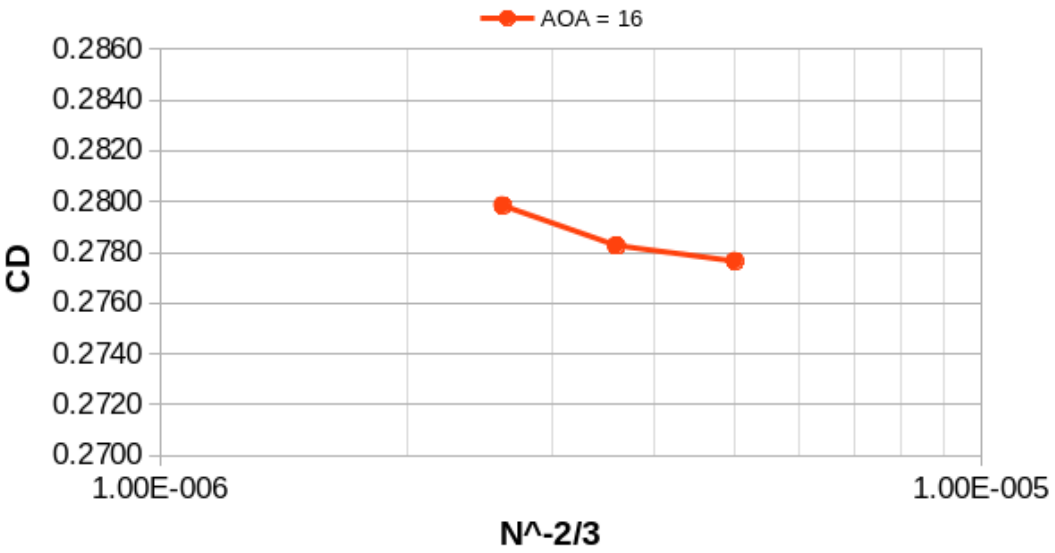
- Drag vs. grid point no.



Case 1a: Full Chord Flap Gap

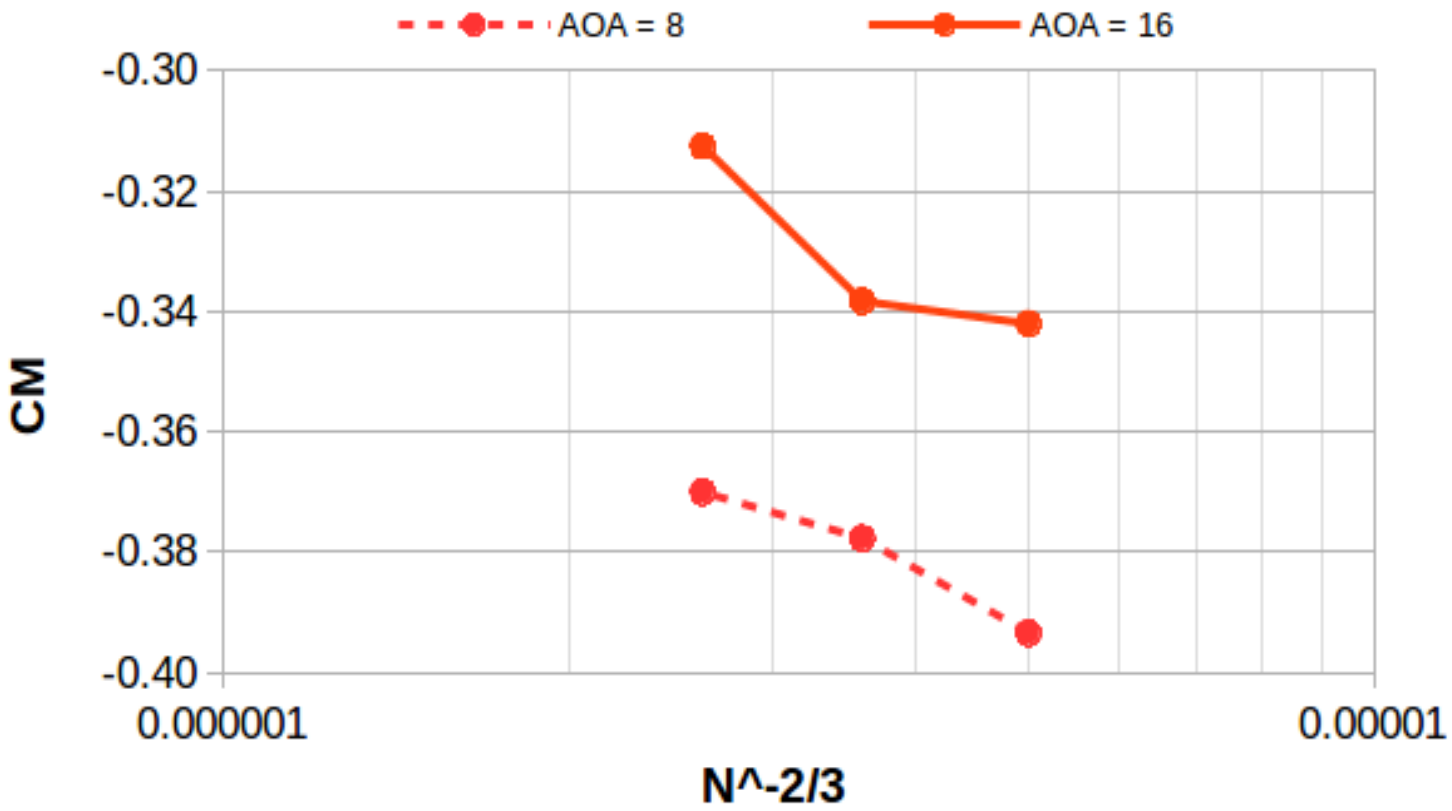
- Drag vs. grid point no.





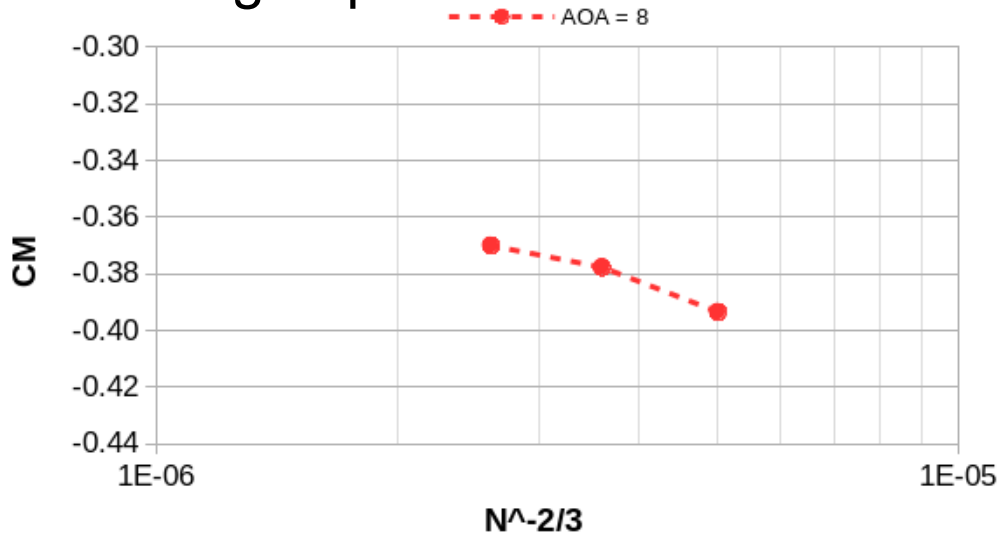
Case 1a: Full Chord Flap Gap

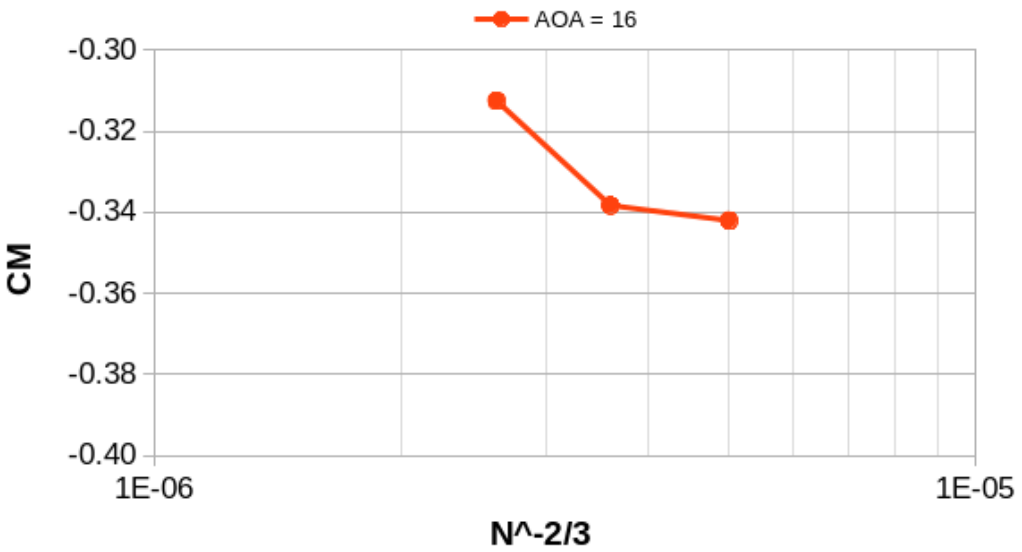
- Pitching Moment vs. grid point no.



Case 1a: Full Chord Flap Gap

- Pitching Moment vs. grid point no.

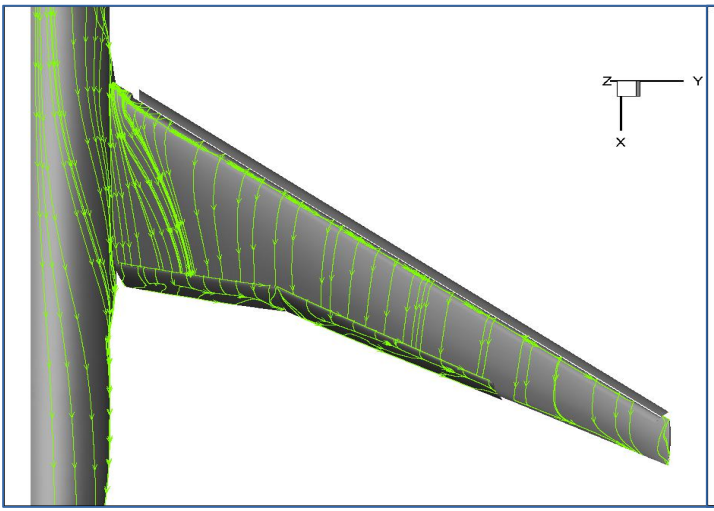




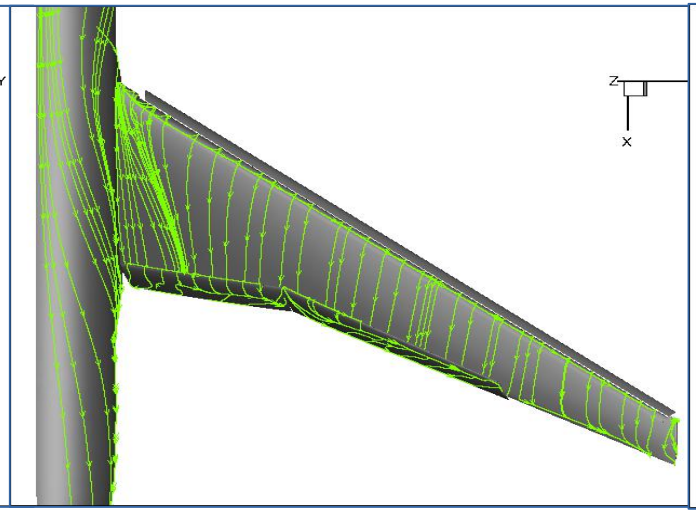
Case 1a: Full Chord Flap Gap Shear stress lines

- AOA = 8 deg.

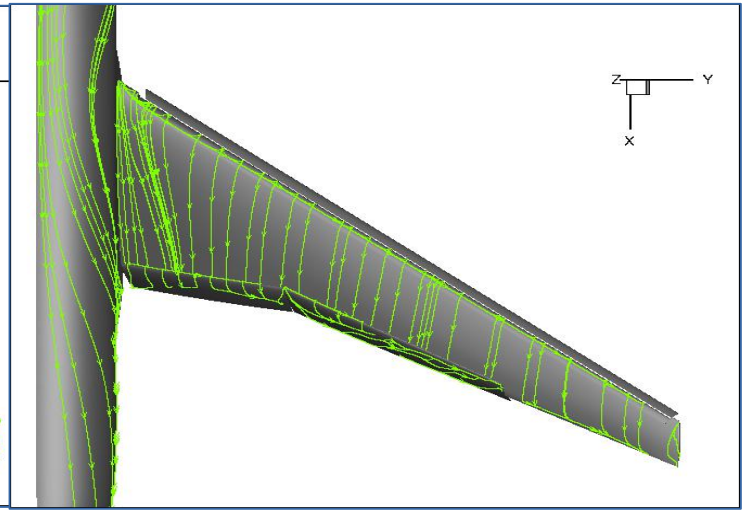
- Coarse mesh



- Medium mesh



- Fine mesh



Case 1a: Full Chord Flap Gap Shear stress lines

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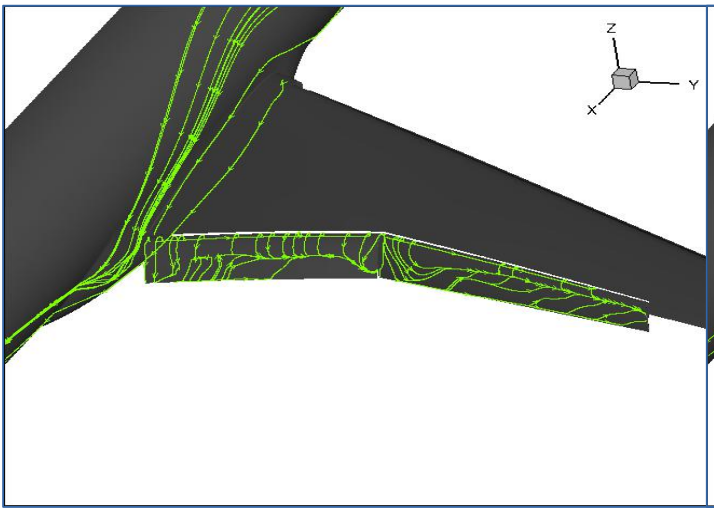
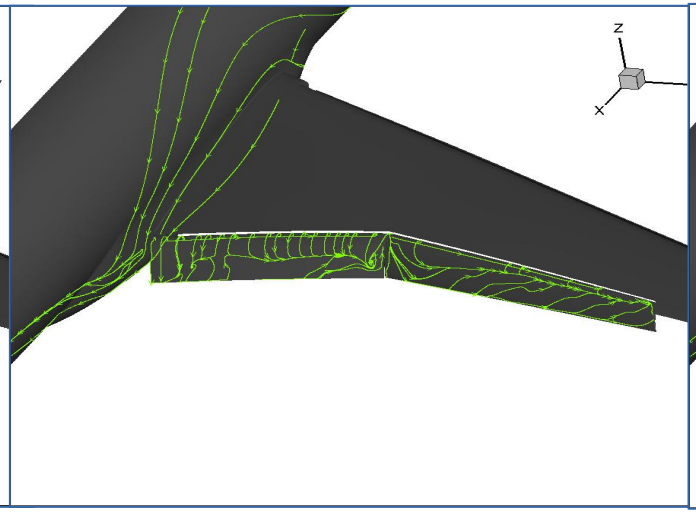
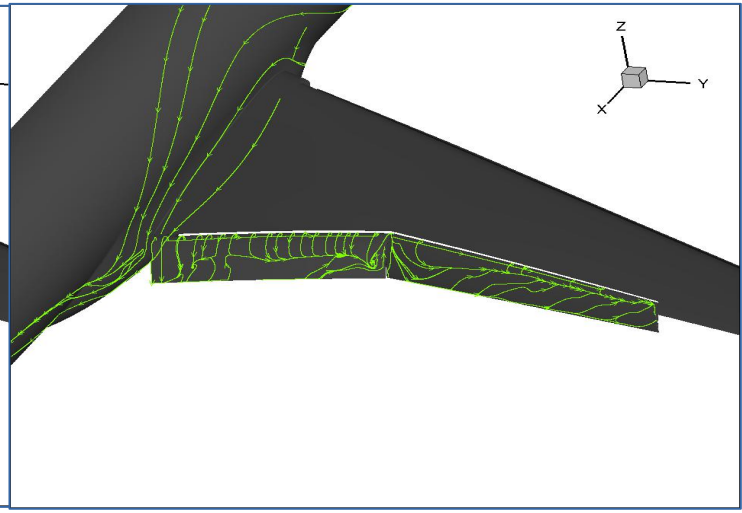


- Medium mesh



- Fine mesh

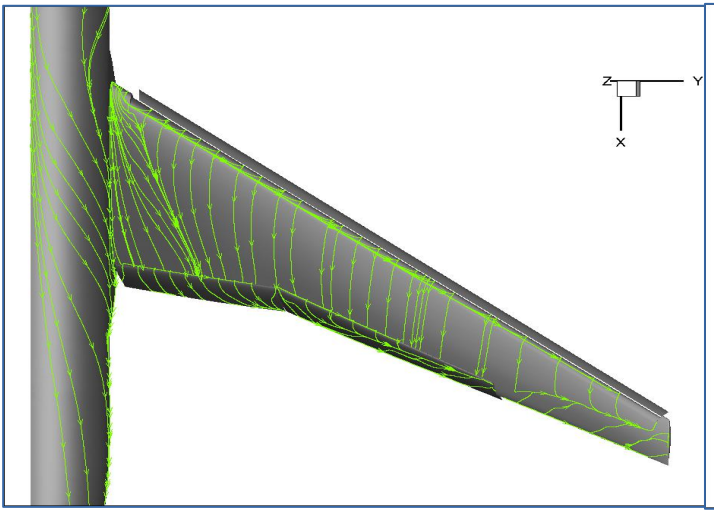


- The inboard flap and outboard flap present a flow detachment

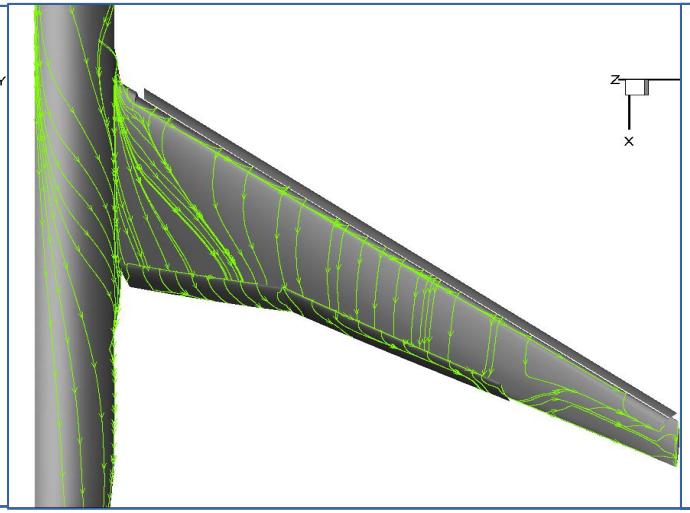
Case 1a: Full Chord Flap Gap Shear stress lines

- AOA = 16 deg.

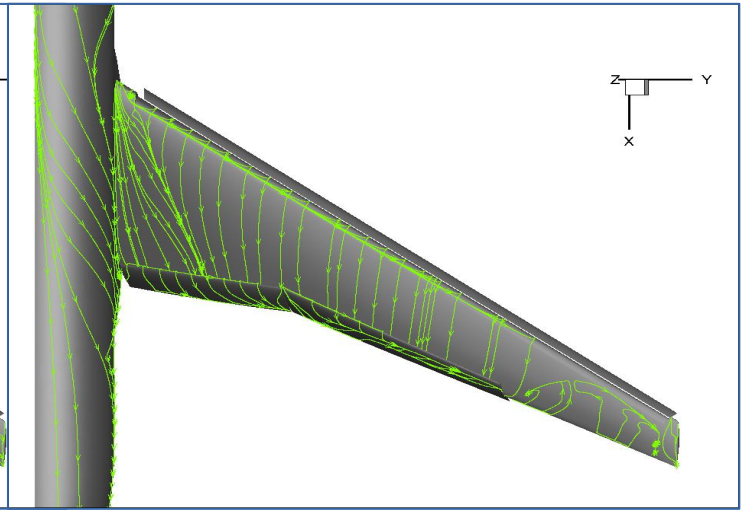
- Coarse mesh



- Medium mesh



- Fine mesh

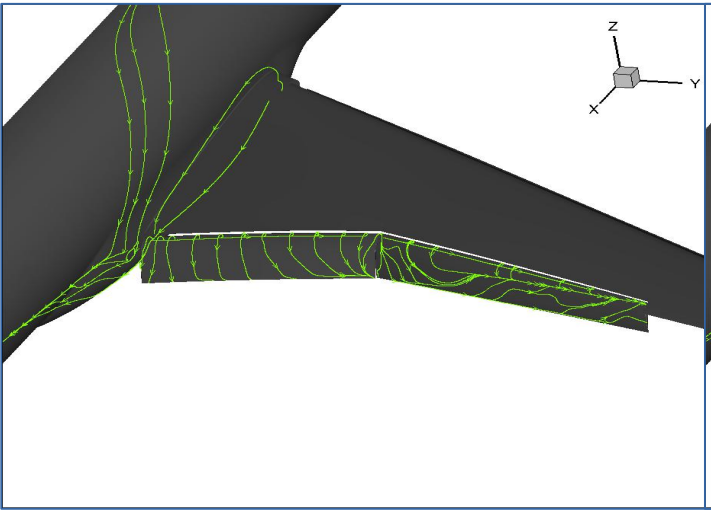


- The flow detachment at the aileron region increases as the mesh is refined.

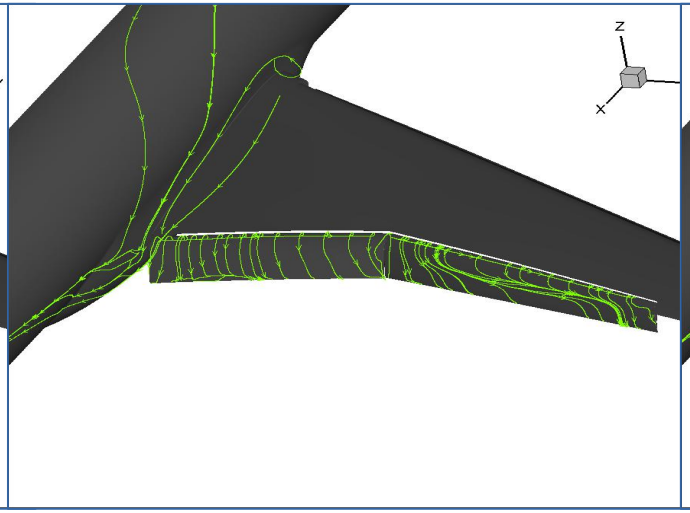
Case 1a: Full Chord Flap Gap Shear stress lines

- AOA = 16 deg.

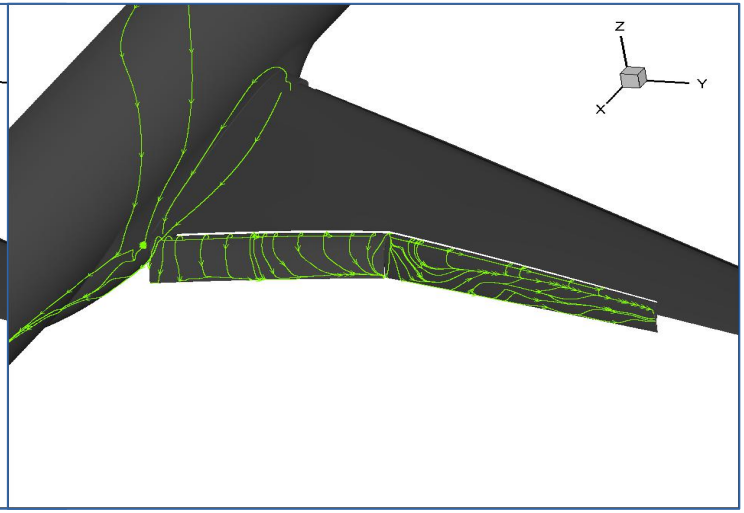
- Coarse mesh



- Medium mesh

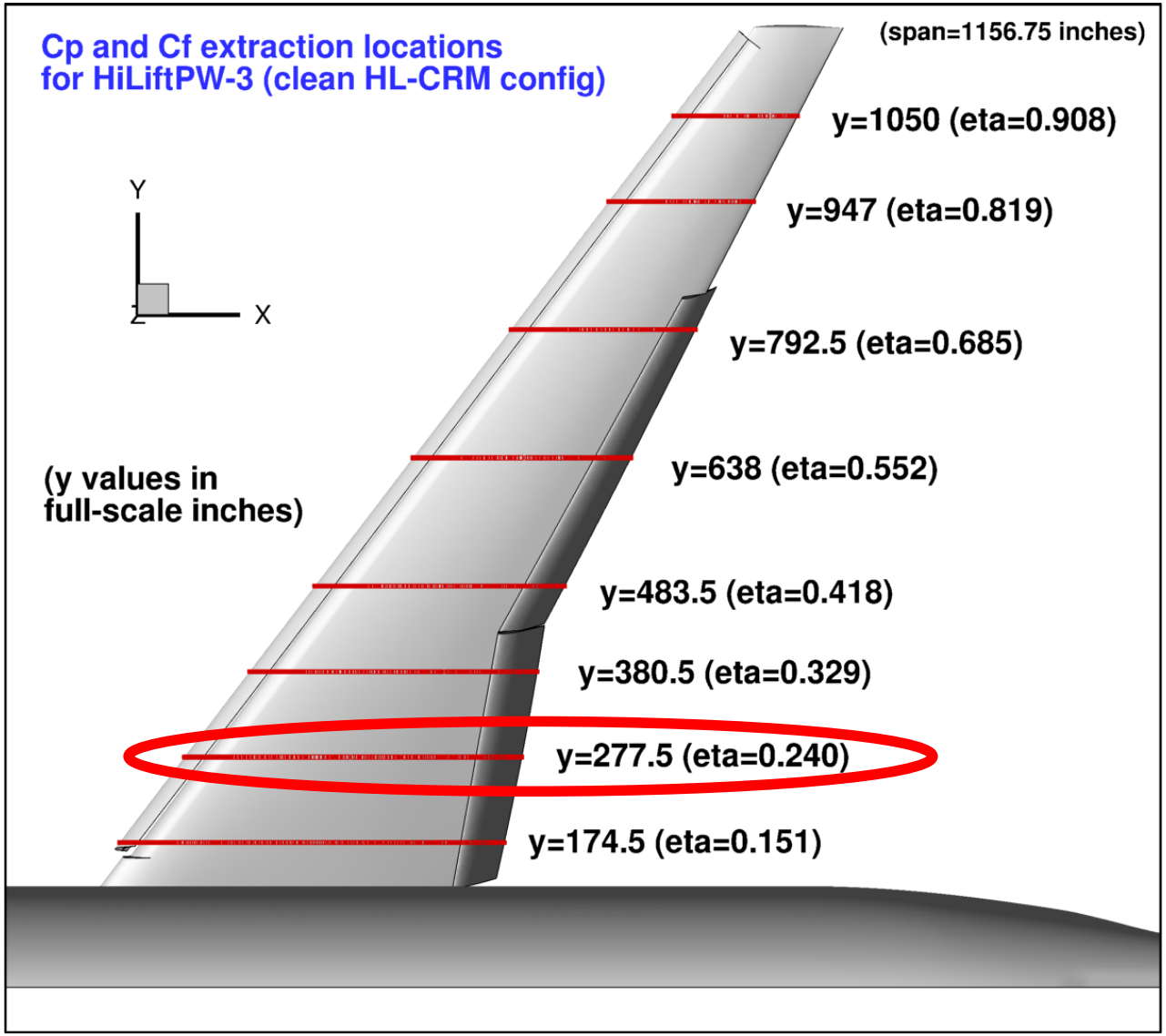


- Fine mesh



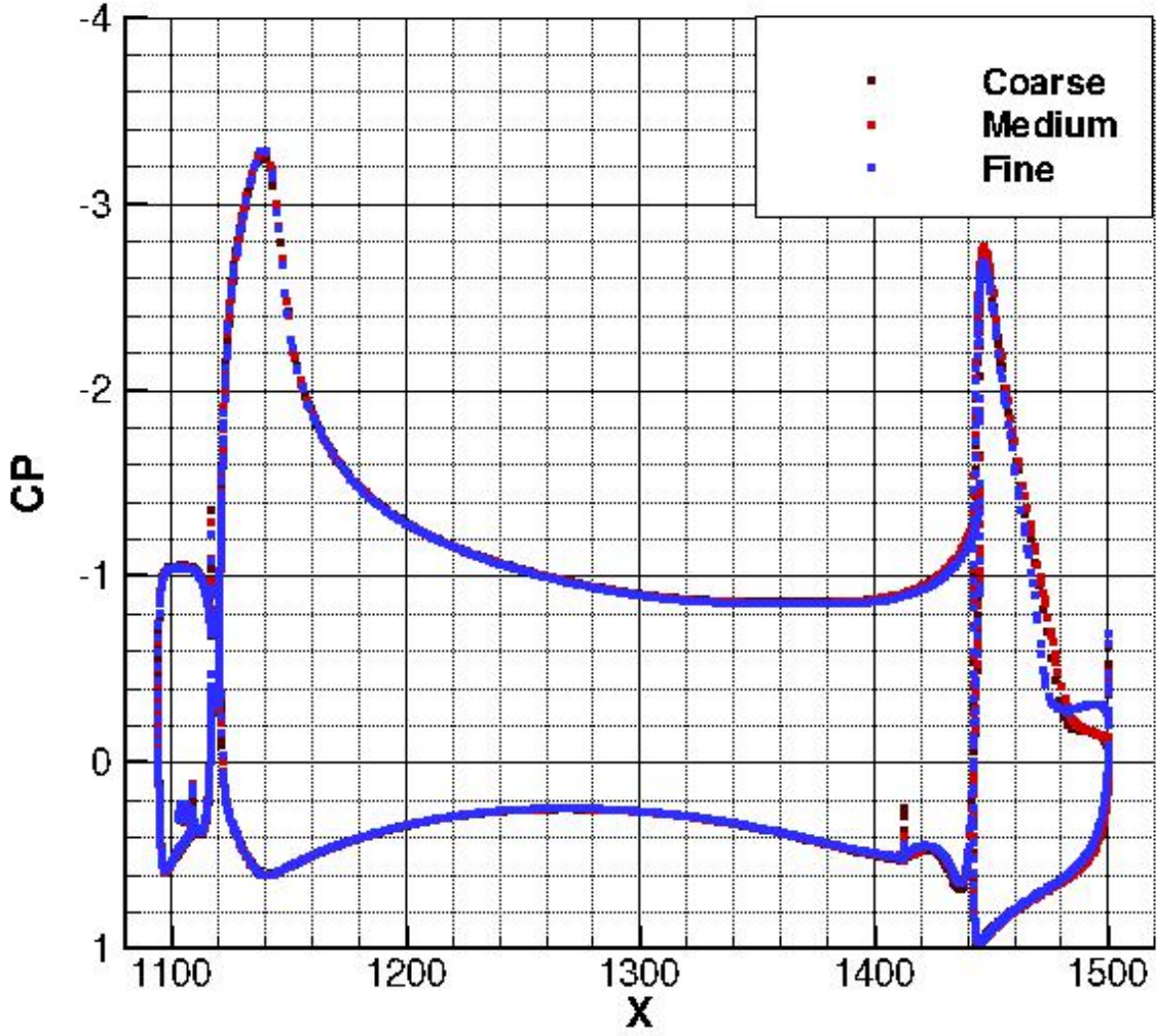
- The outboard flap present a flow detachment

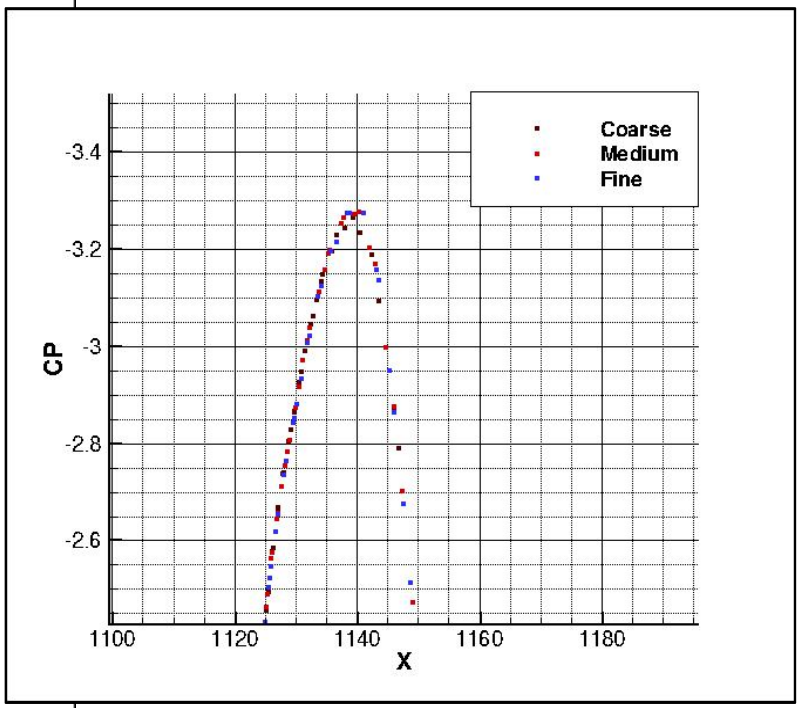
Case 1a: Full Chord Flap Gap CP distribution



Case 1a: Full Chord Flap Gap CP distribution

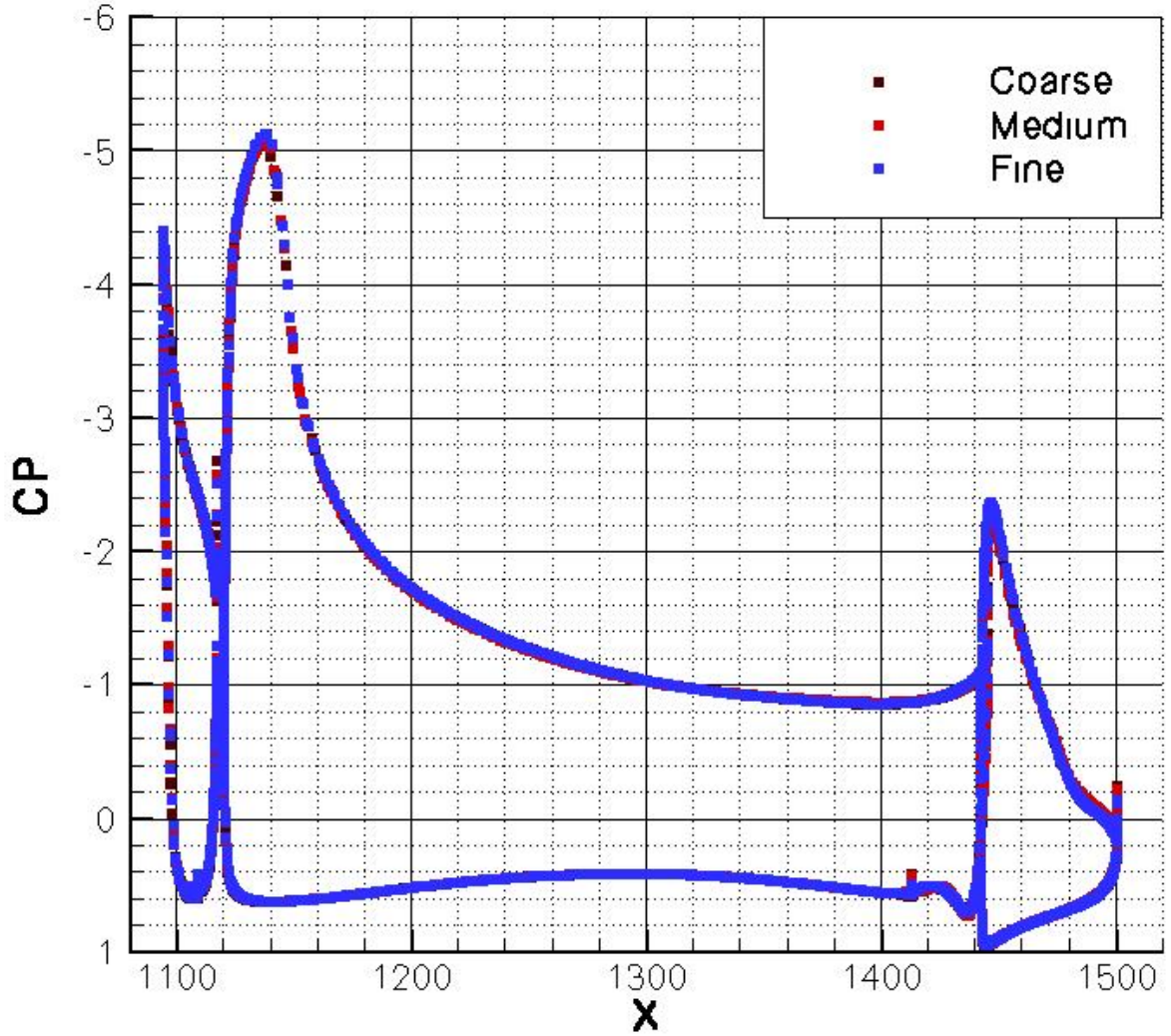
AOA = 8 deg

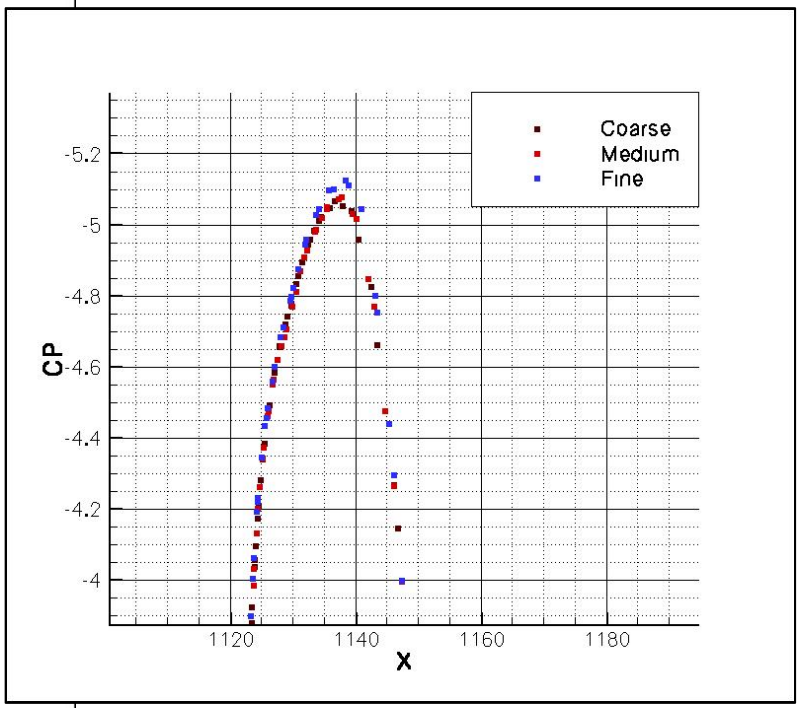




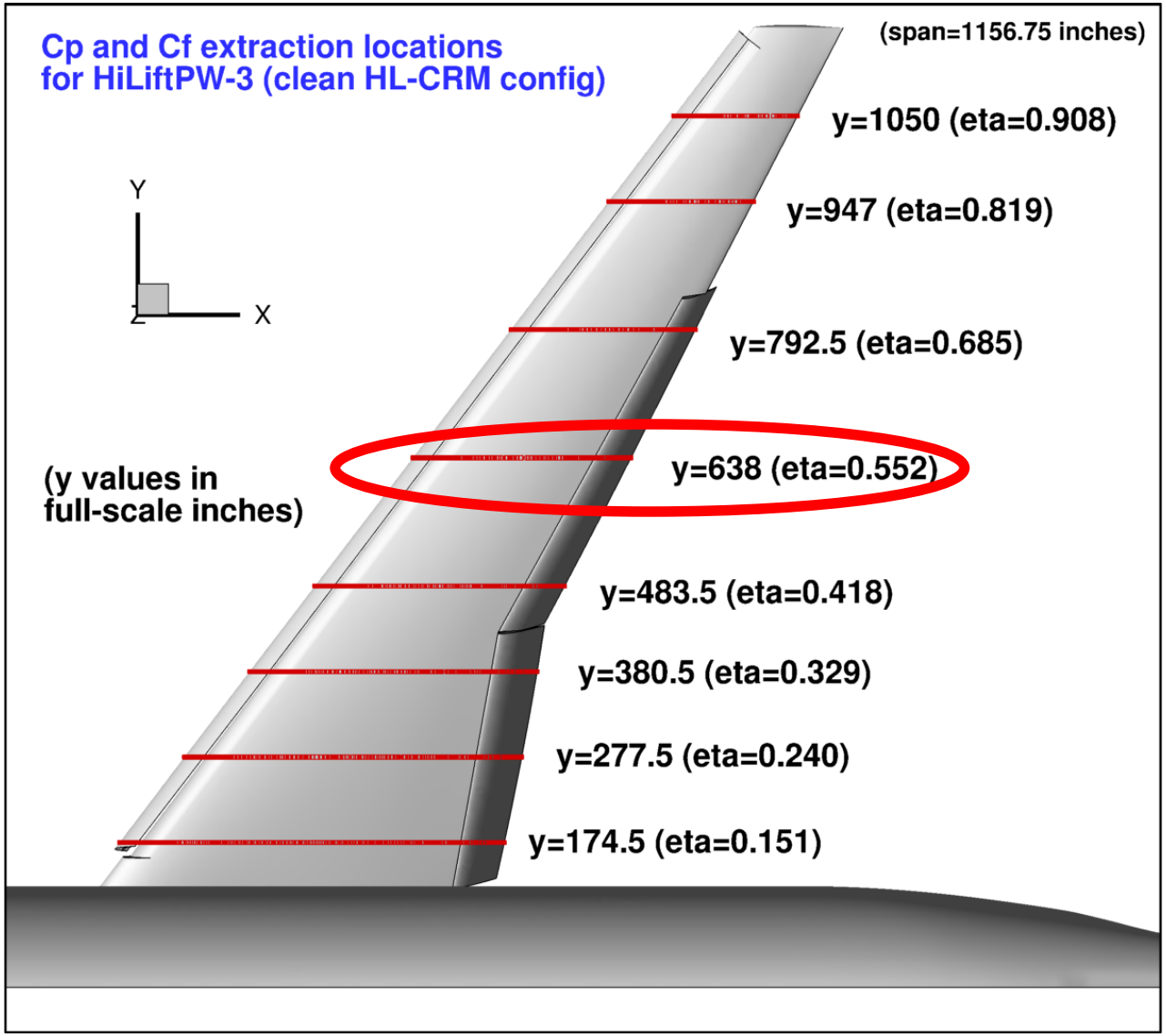
Case 1a: Full Chord Flap Gap CP distribution

AOA = 16 deg



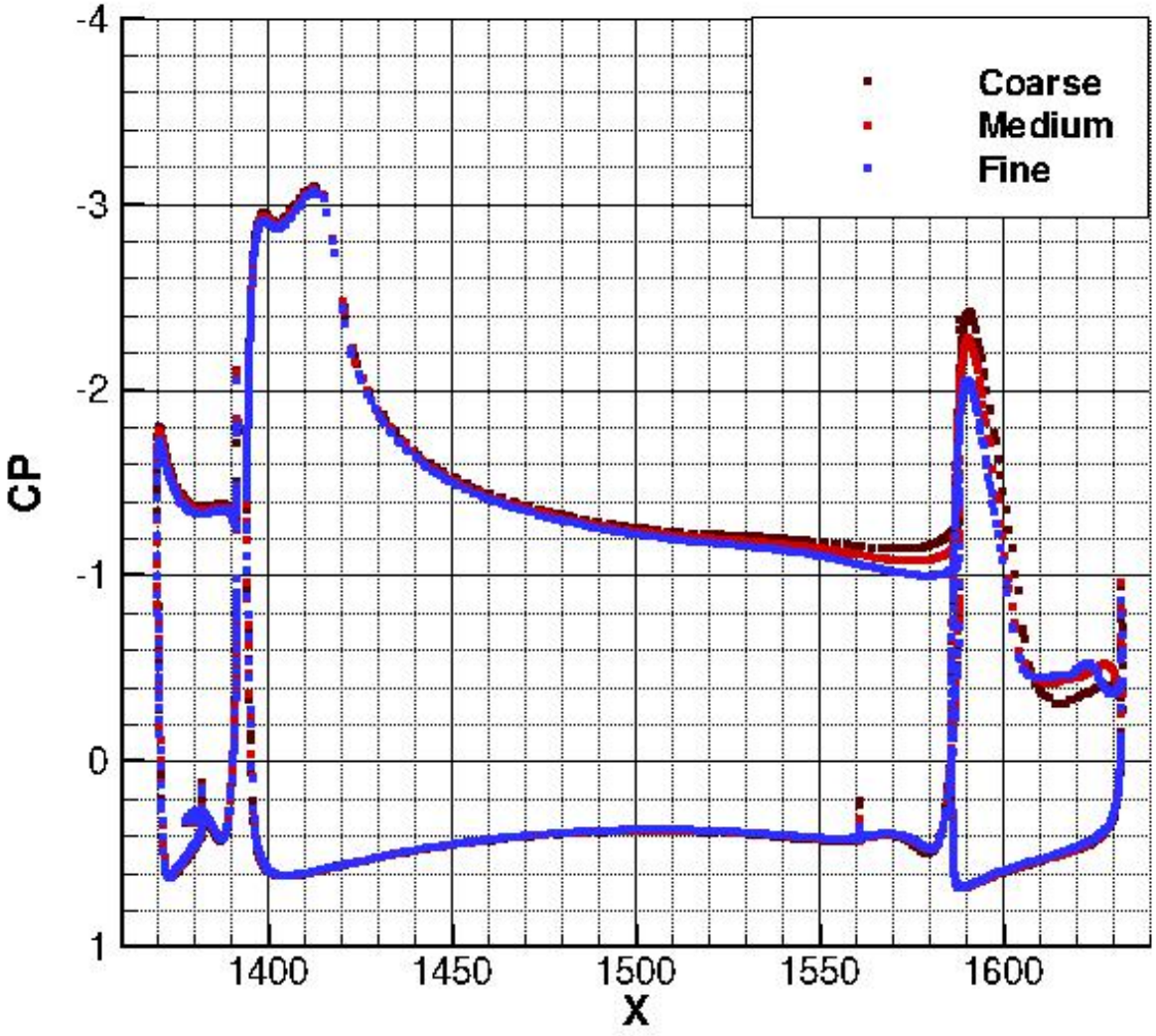


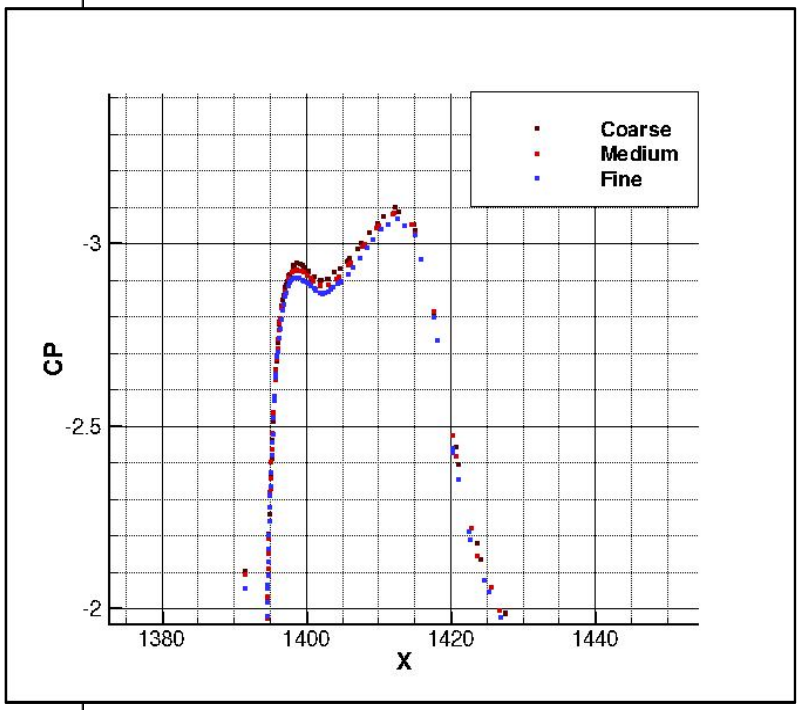
Case 1a: Full Chord Flap Gap CP distribution



Case 1a: Full Chord Flap Gap CP distribution

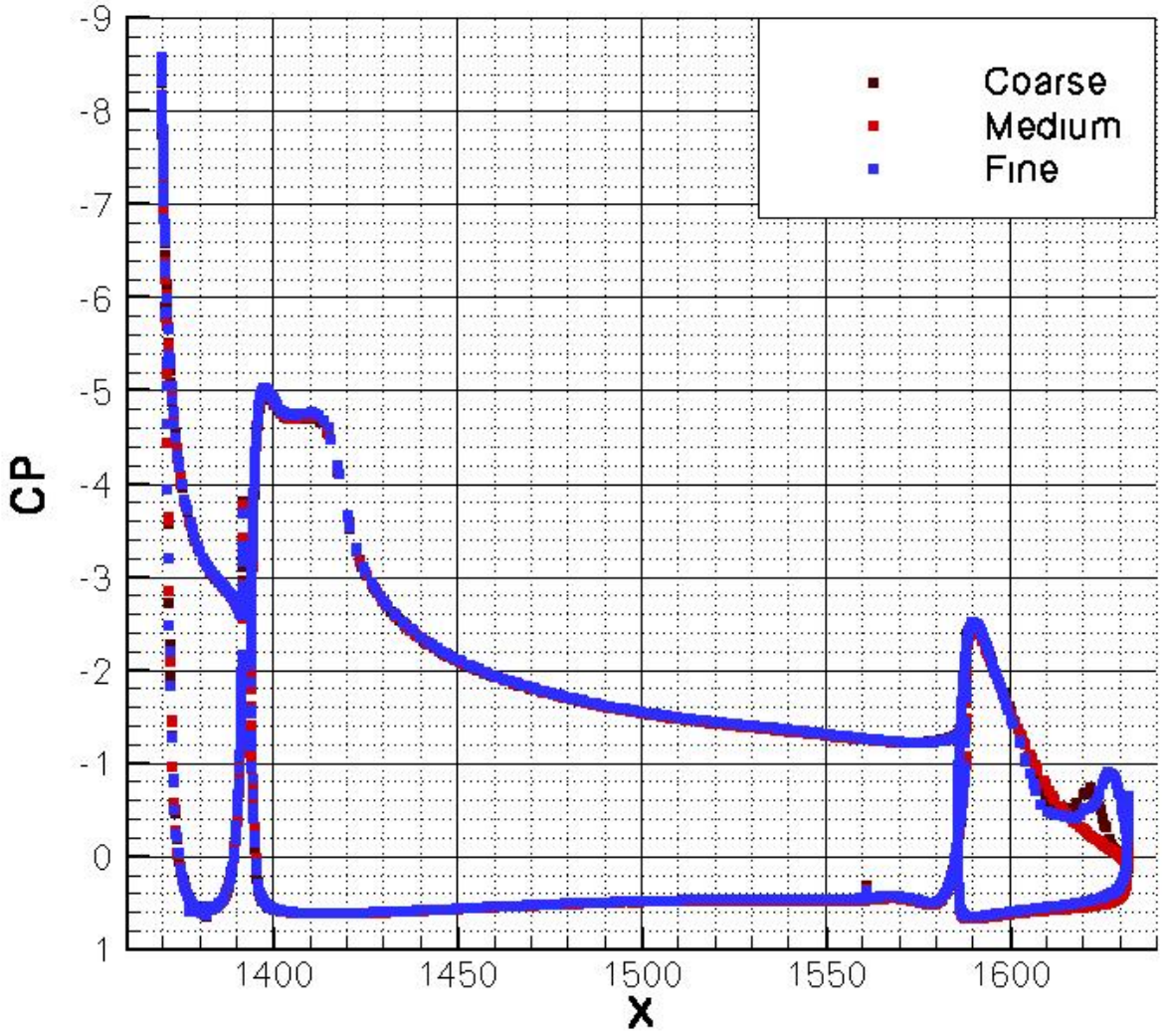
AOA = 8 deg

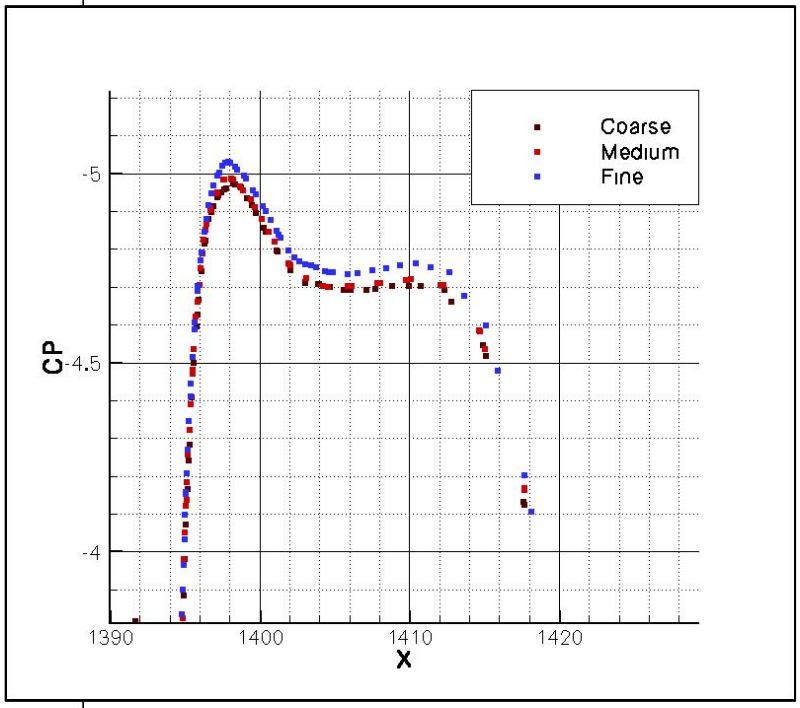




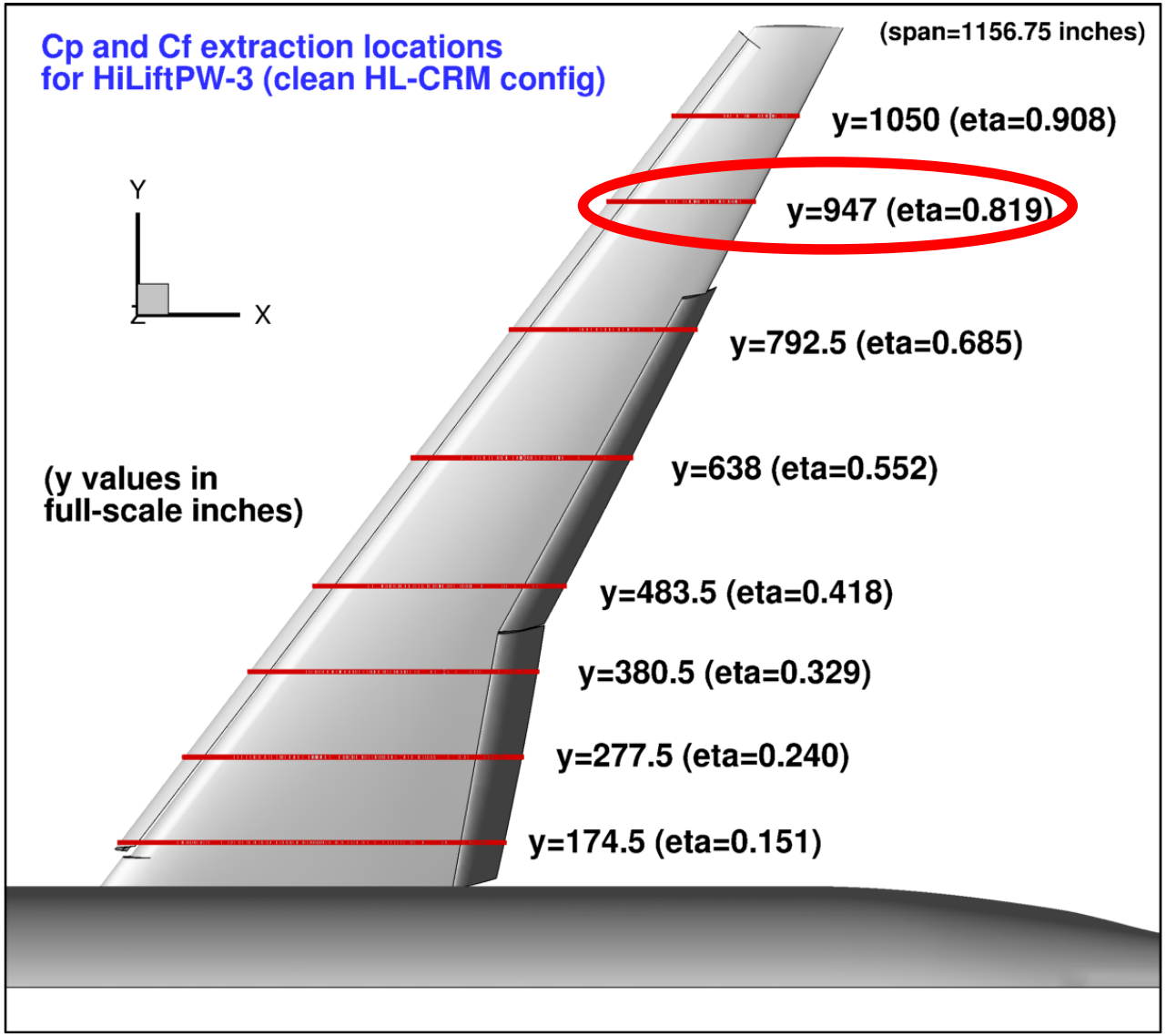
Case 1a: Full Chord Flap Gap CP distribution

AOA = 16 deg



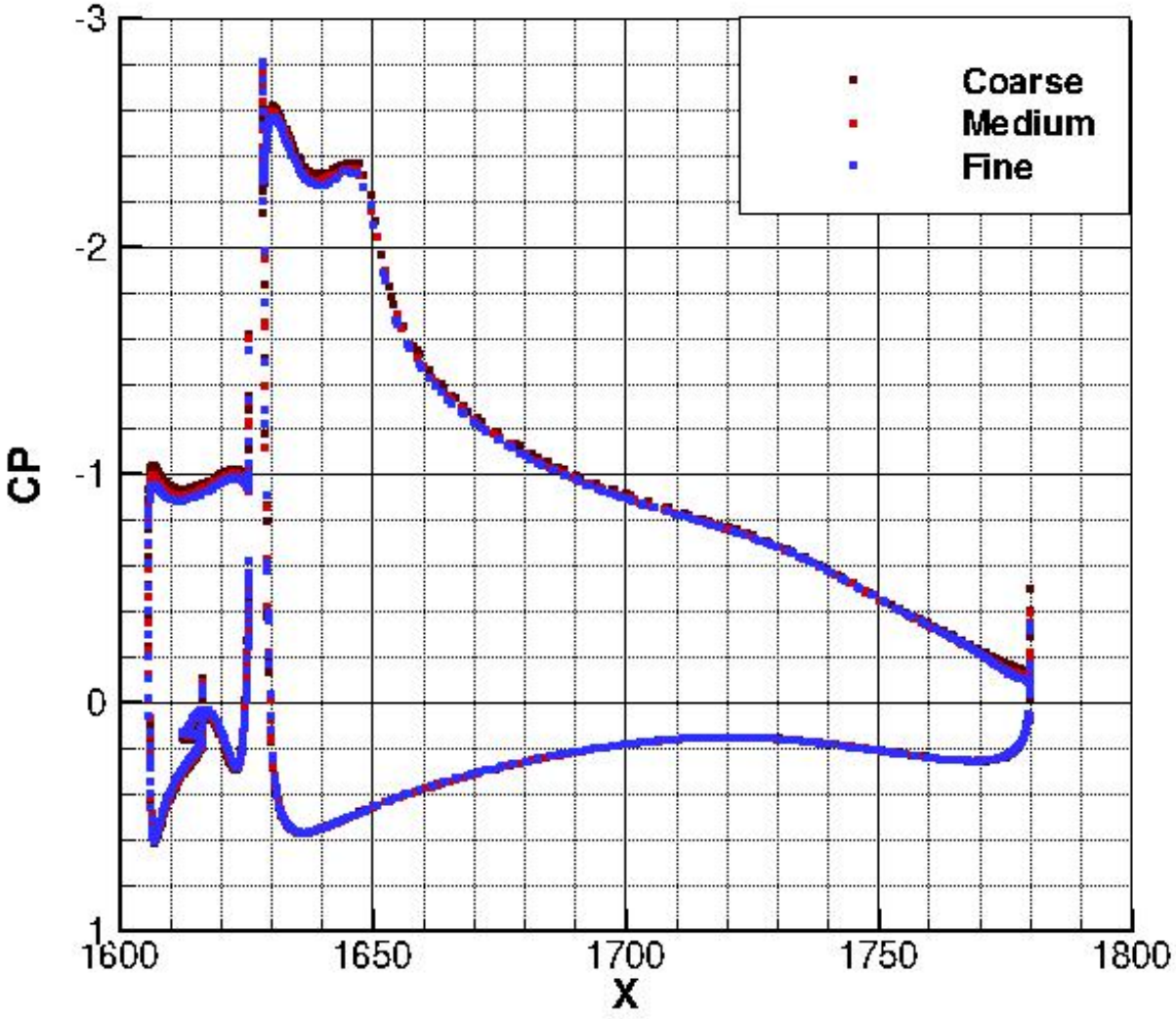


Case 1a: Full Chord Flap Gap CP distribution



Case 1a: Full Chord Flap Gap CP distribution

AOA = 8 deg



Case 1a: Full Chord Flap Gap CP distribution

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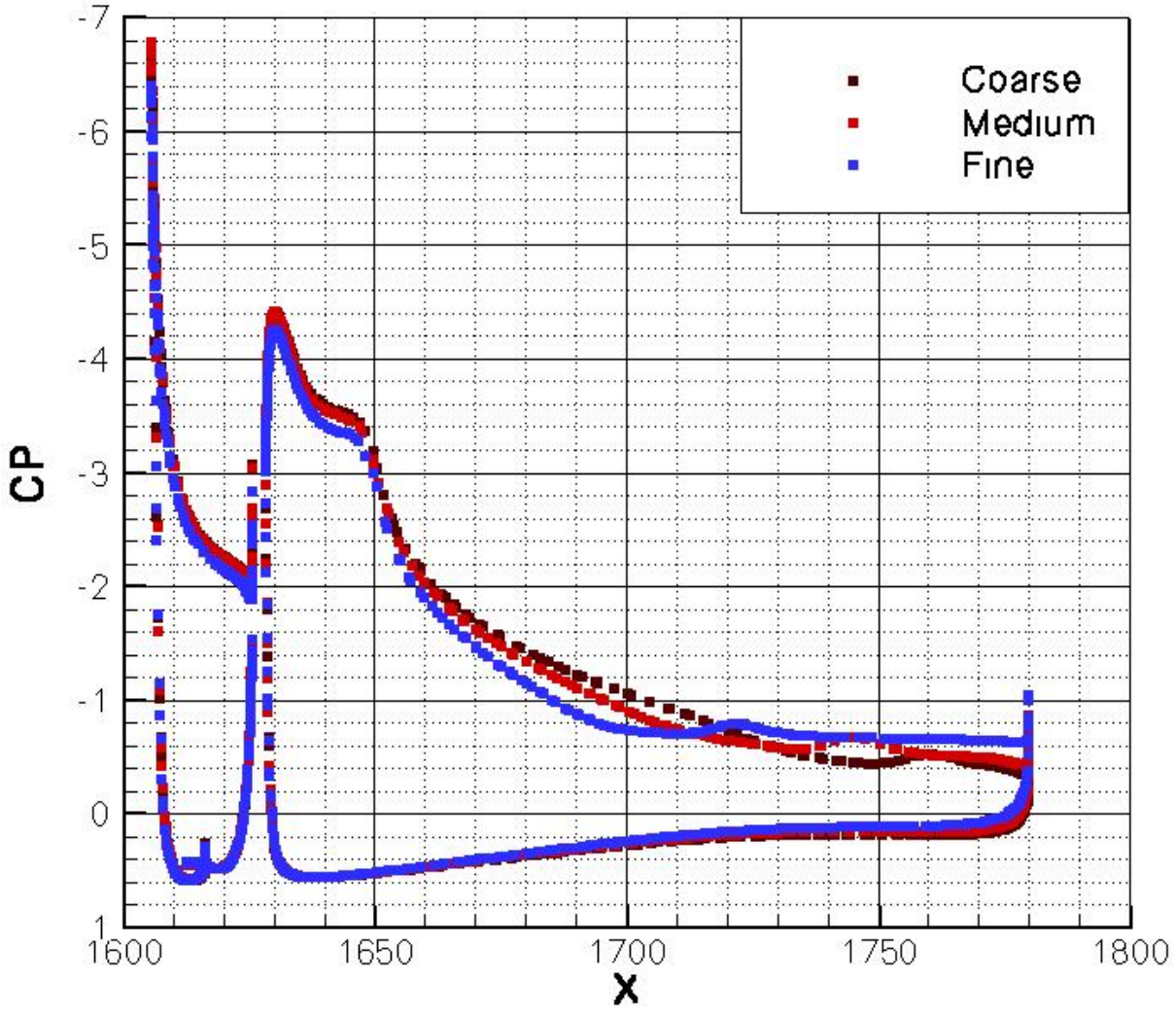


Cases 2a and 2c

- Case 2a - JAXA Standard Model (JSM) Nacelle/Pylon OFF (WB).

- Case 2c - JAXA Standard Model (JSM) Nacelle/Pylon ON (WBPN).

- MAC = 529.2 mm
- Wing semi-span = 2300.0 mm
- Sref/2 = 1,123,300.0 mm^2
- MRC : x=2375.7 mm, y=0.0 mm, z=0.0 mm

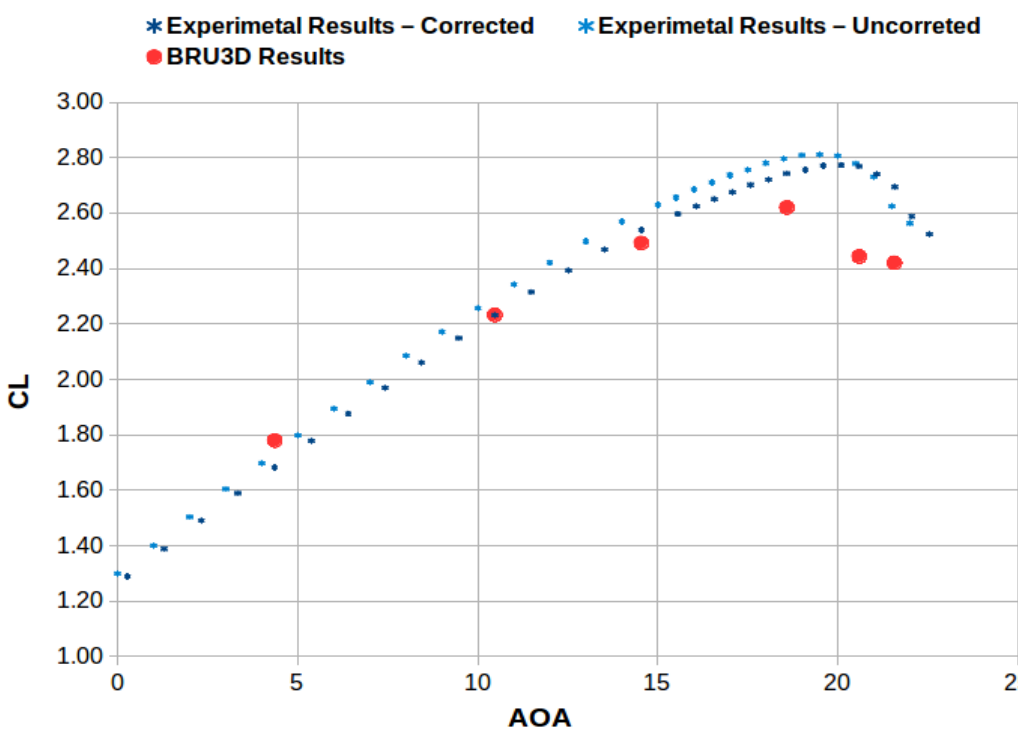
- Mach = 0.172
- Re = 1.93 million
- AOA's = 4.36, 10.47, 14.54, 18.58, 20.59 and 21.57deg

- Mesh : E-JSM_UnstrMixed_ANSA V1

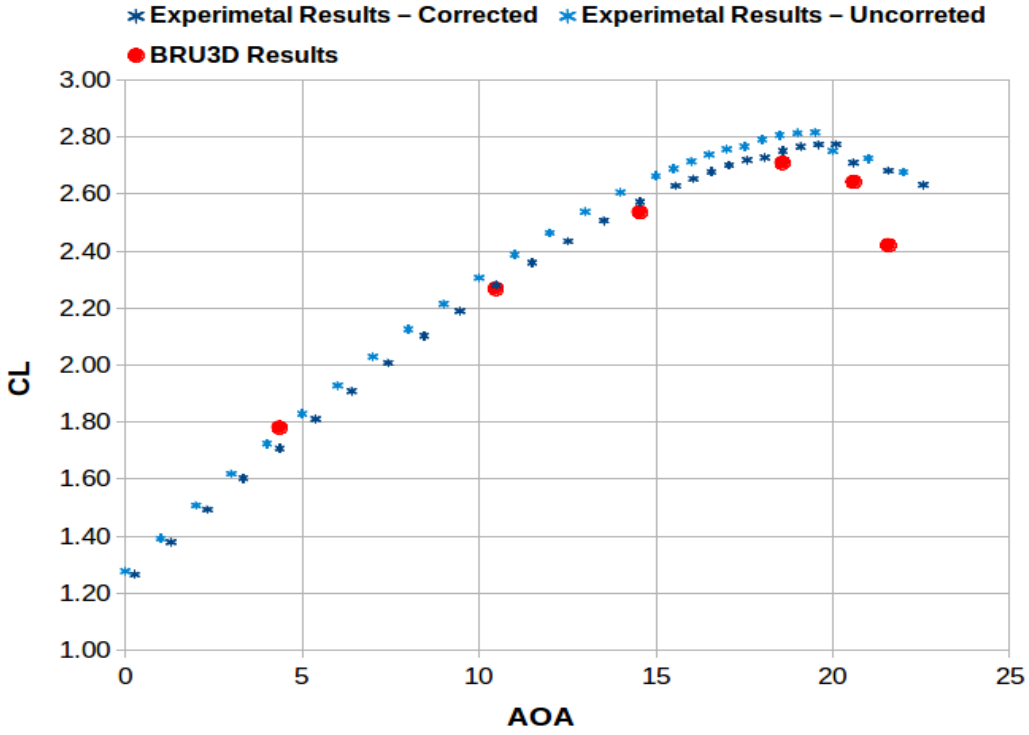
Cases 2a and 2c
Lift Curve

- Lift curve

WB



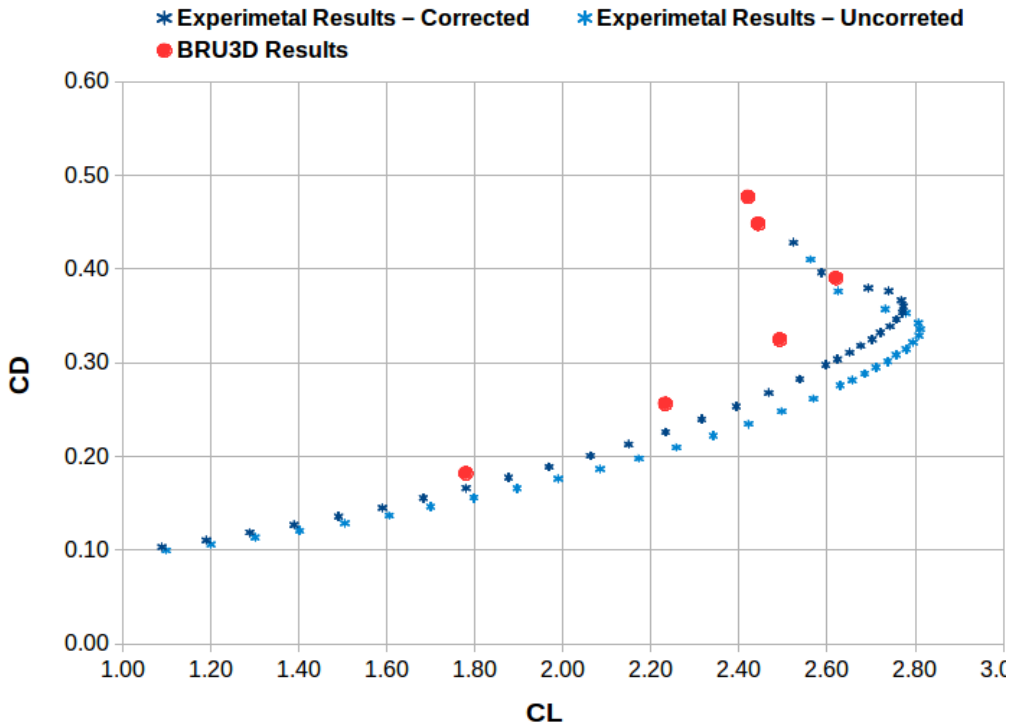
WBPN



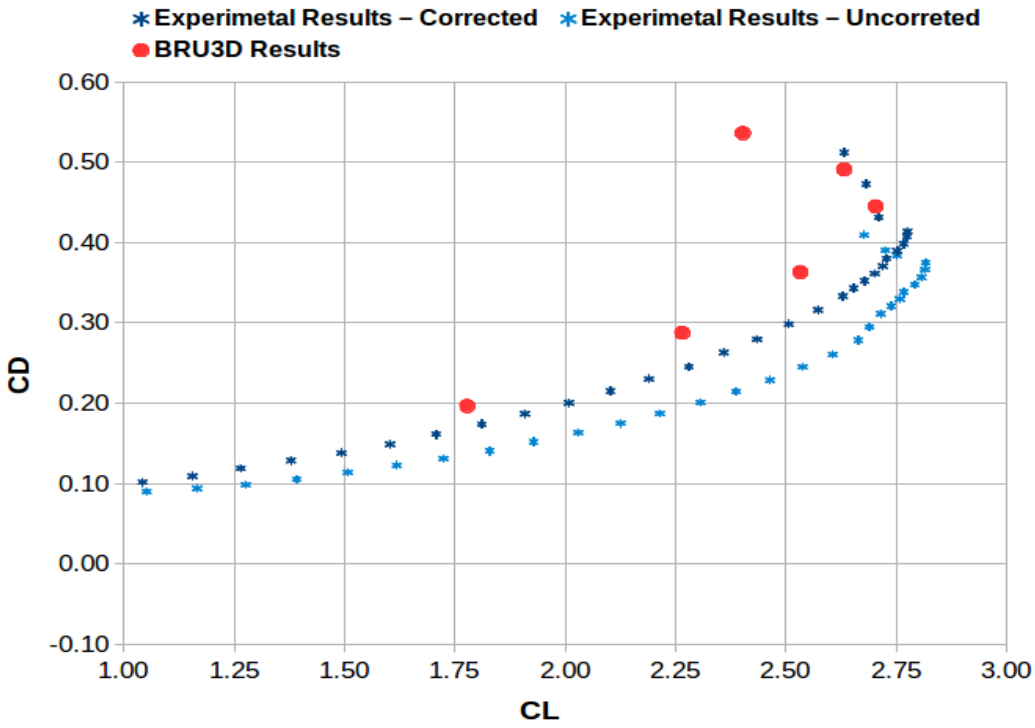
Cases 2a and 2c
Drag Polar

- Drag Polar

WB



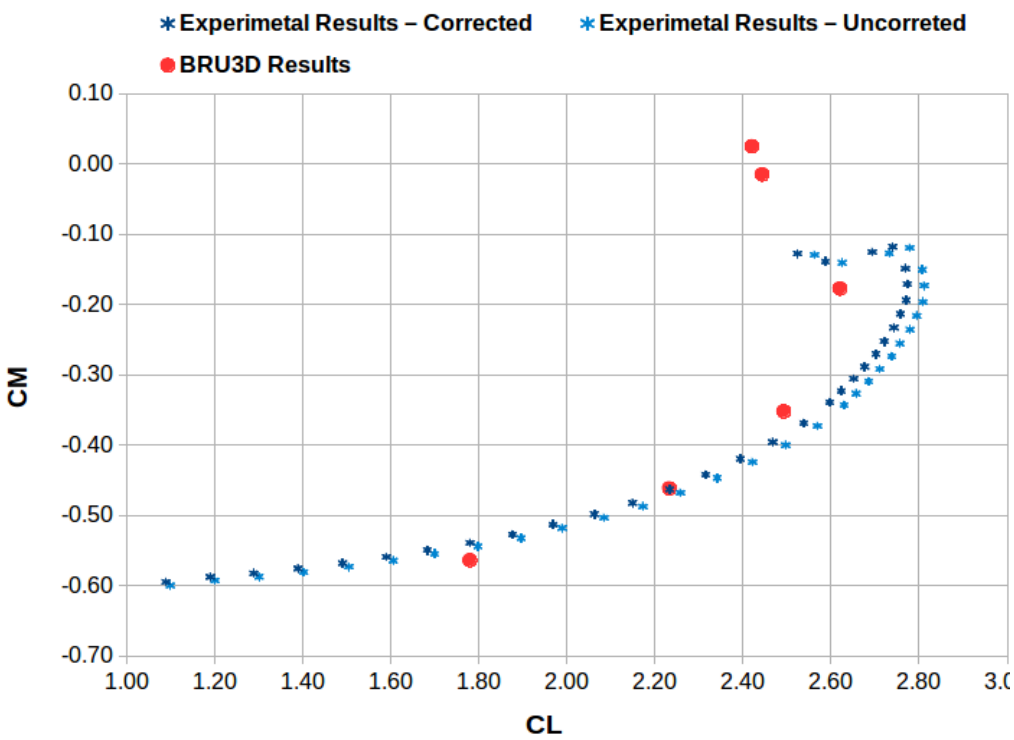
WBPN



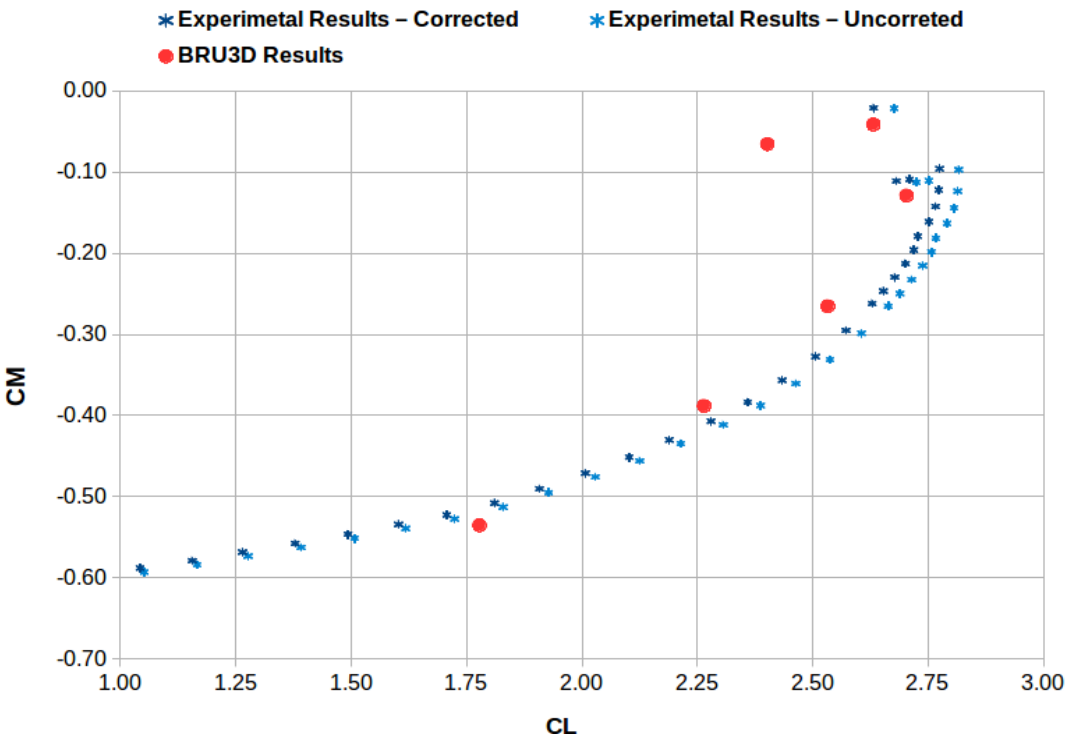
Cases 2a and 2c Pitching Moment

- Pitching Moment

WB

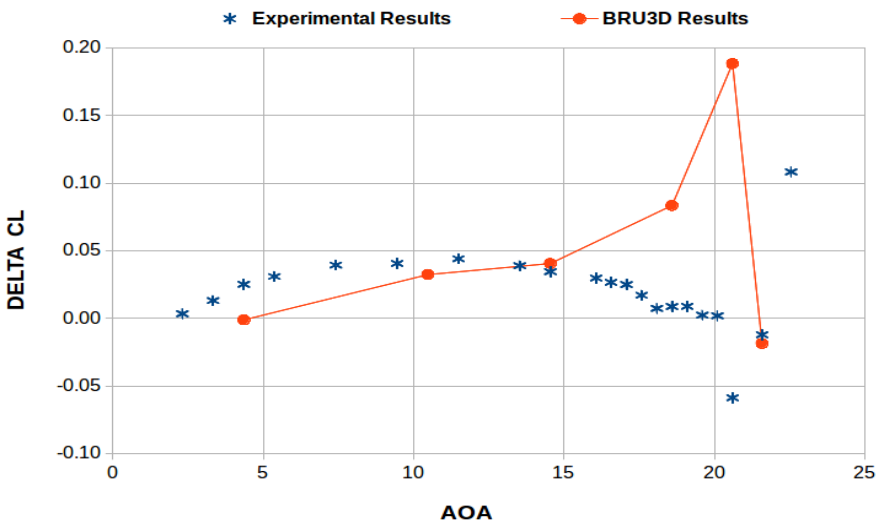


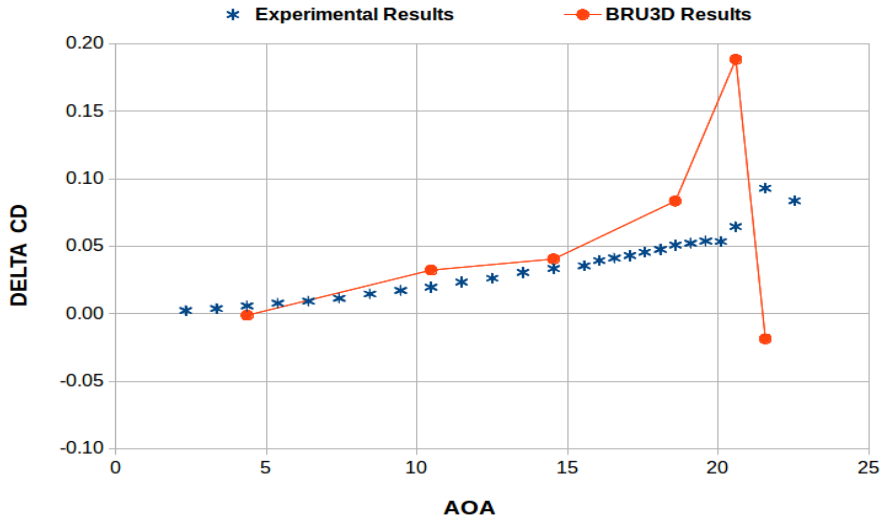
WBPN

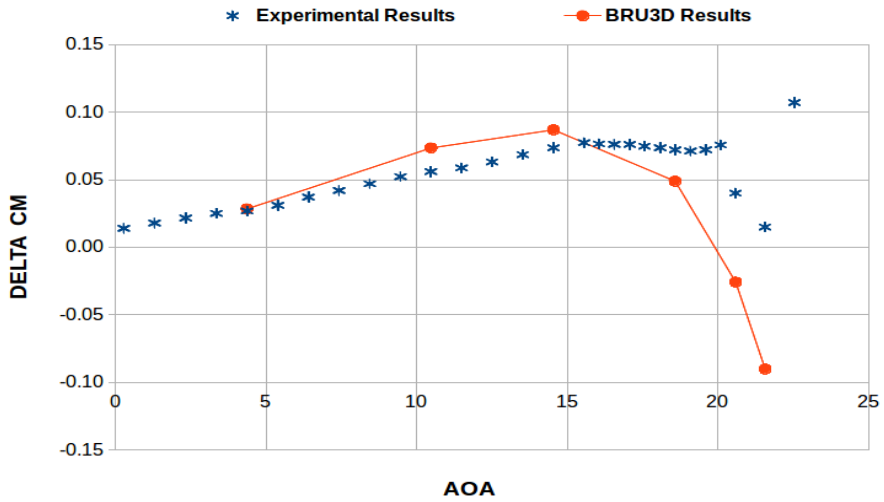


Cases 2a and 2c Delta

- Deltas (WBPN minus WB)

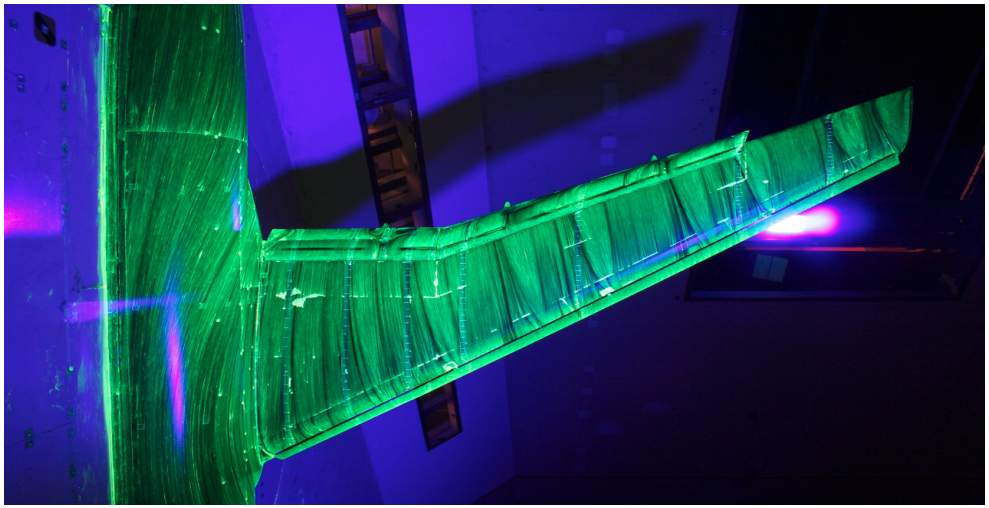


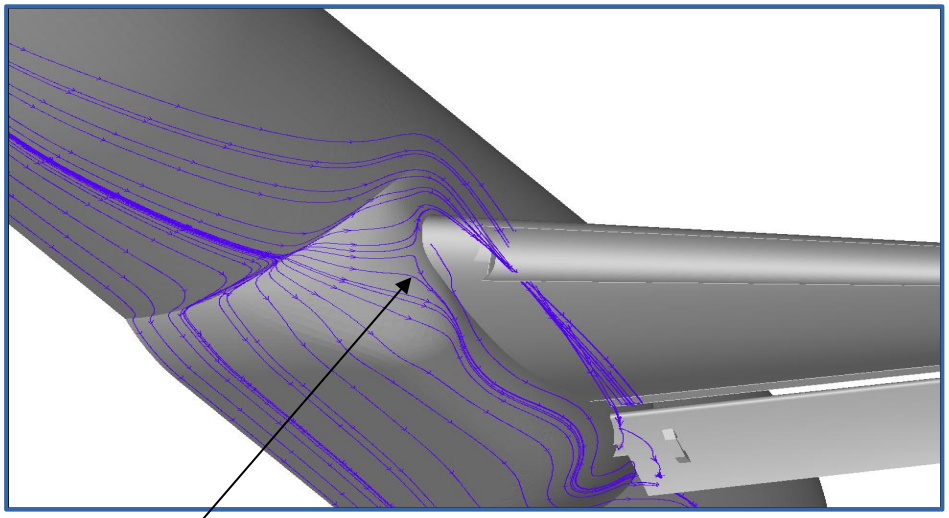


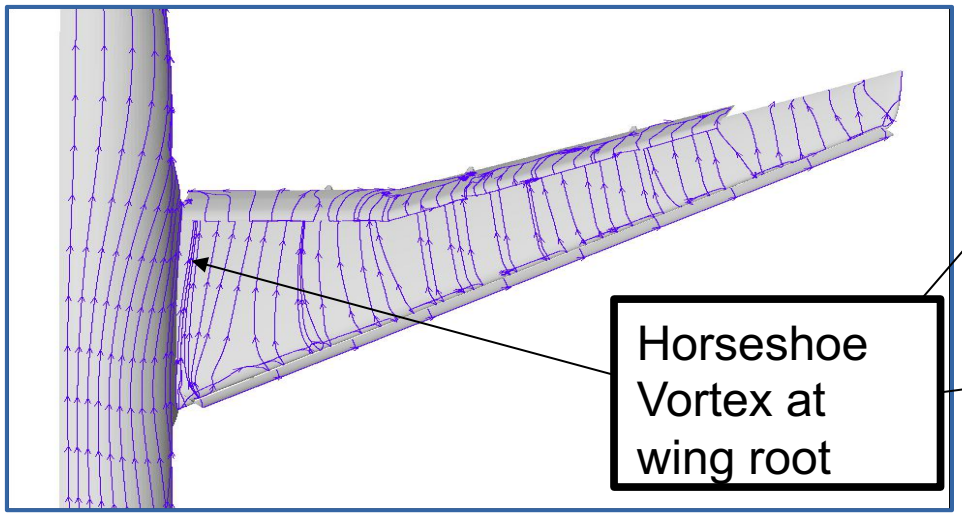


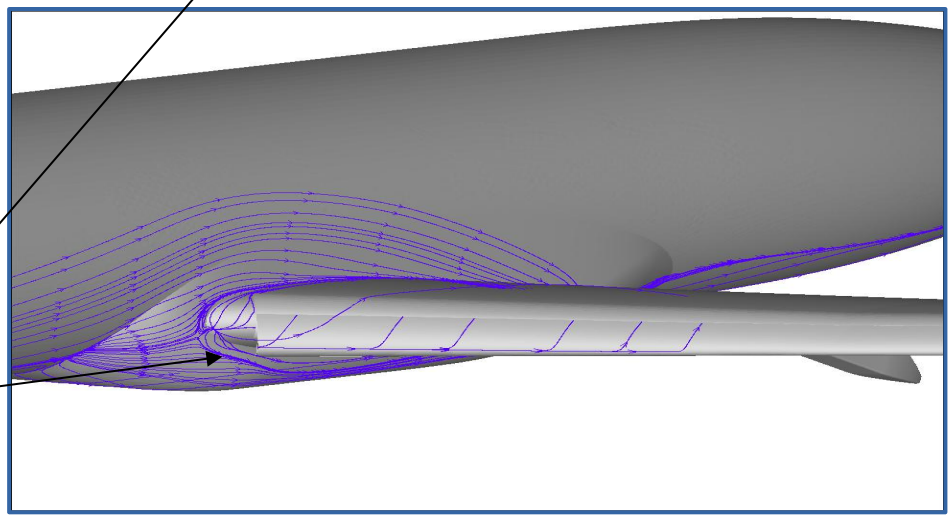
CASE 2a - WB - Oil flow

- WB - AOA = 4.36 deg



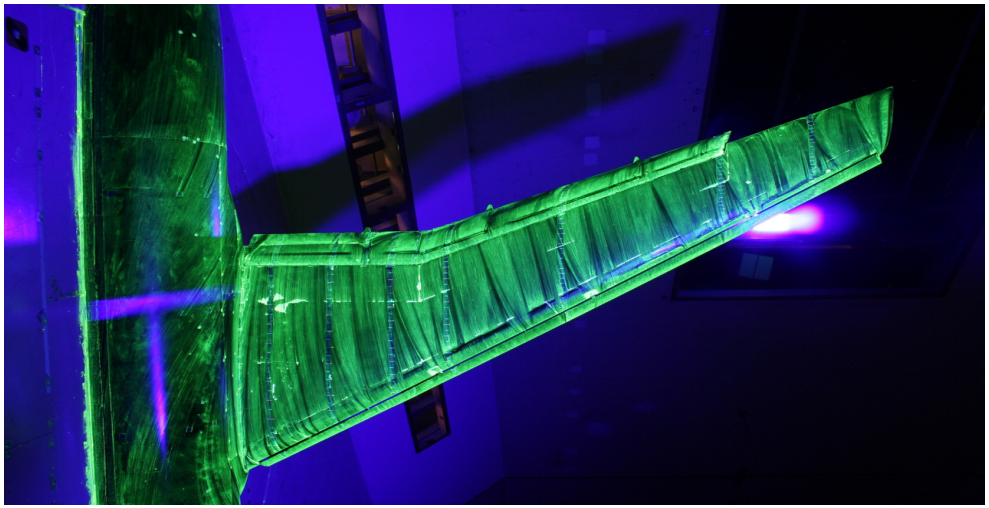


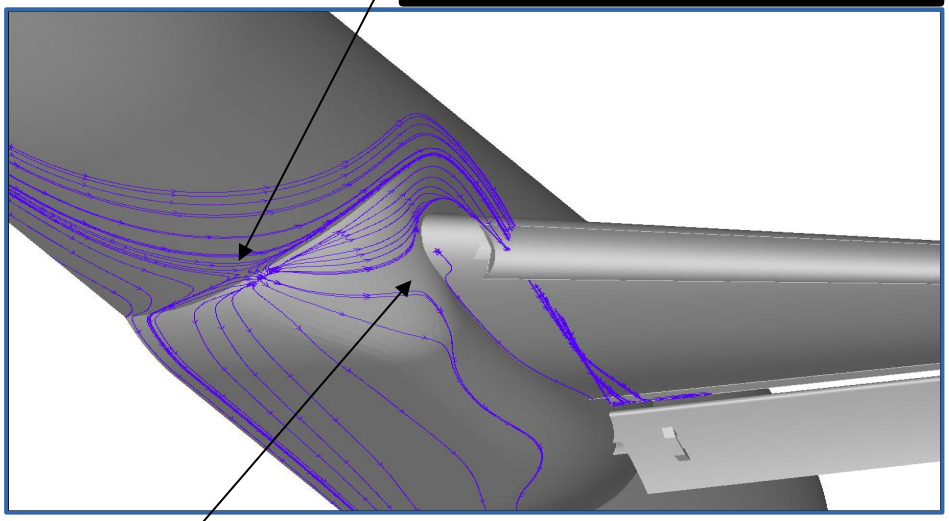


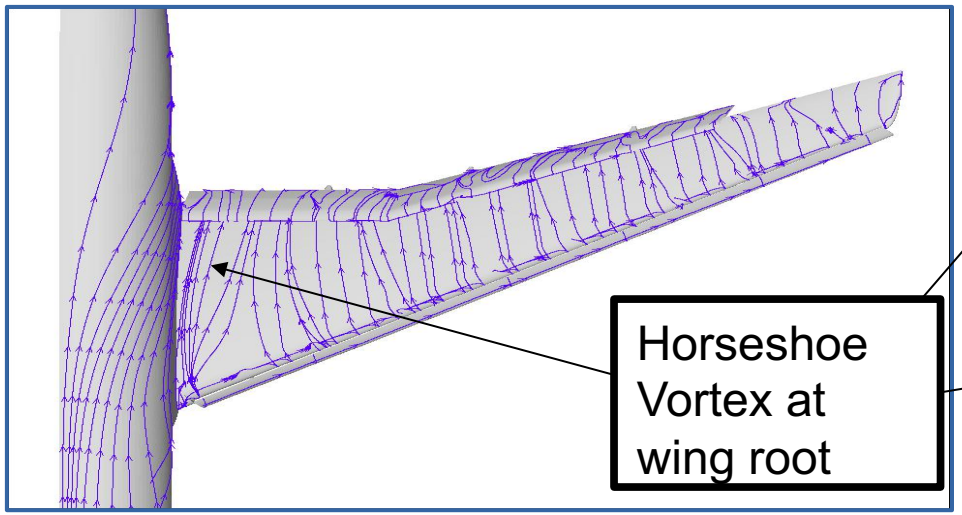


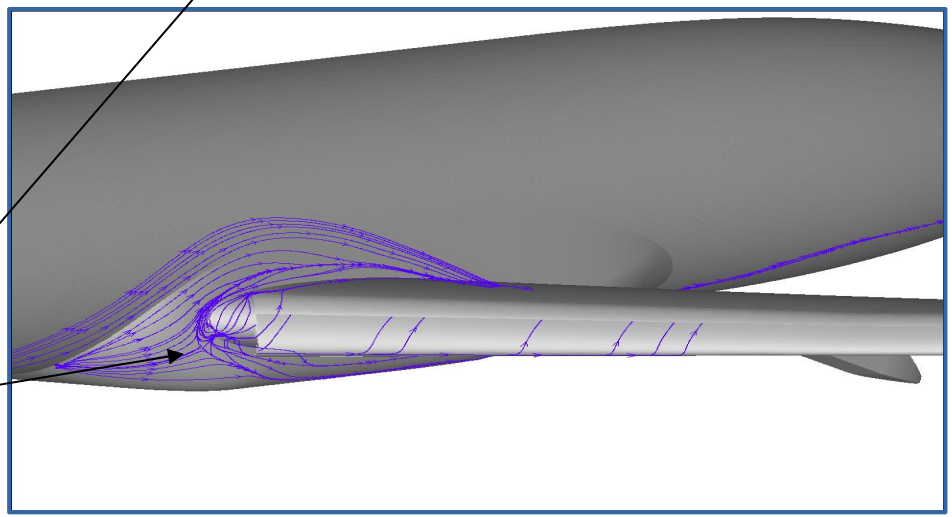
CASE 2a - WB - Oil flow

- WB - AOA = 10.48 deg



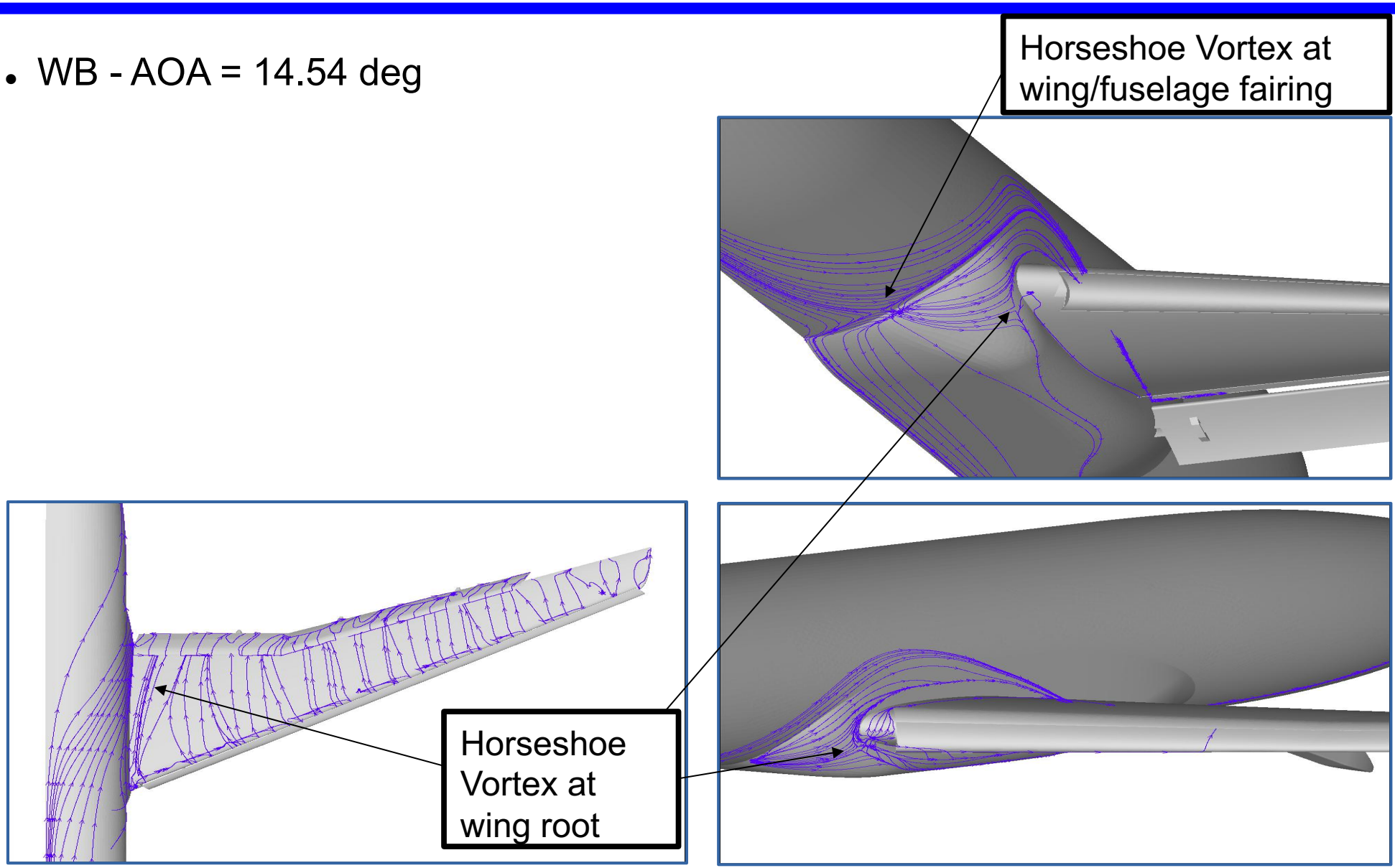






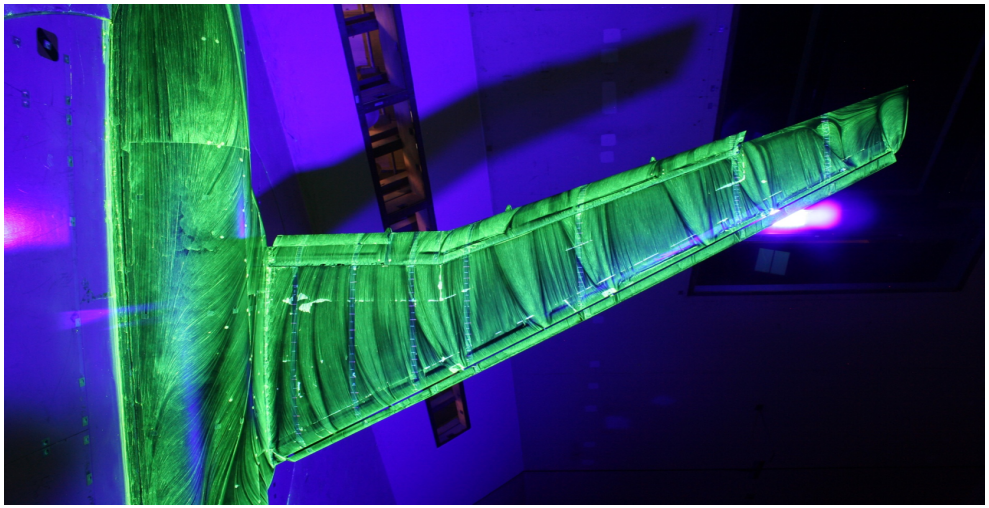
CASE 2a - WB - Oil flow

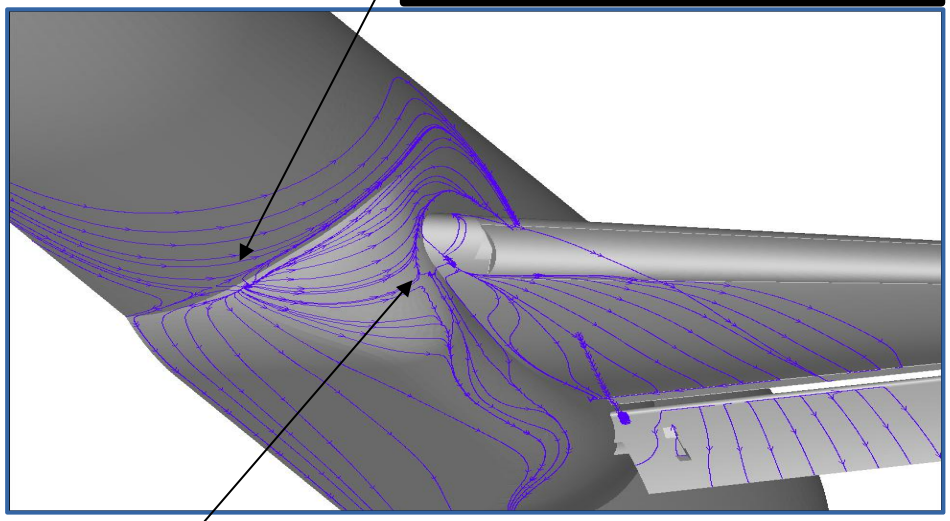
- WB - AOA = 14.54 deg

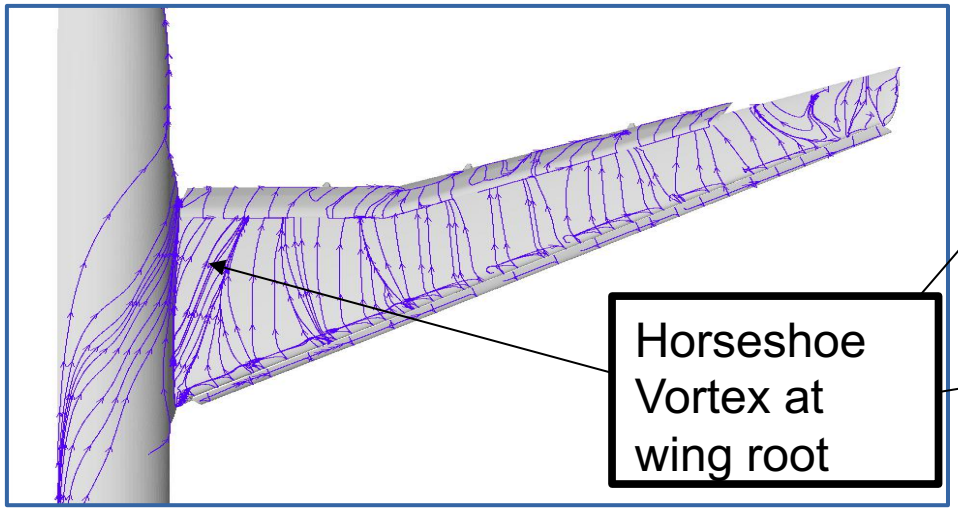


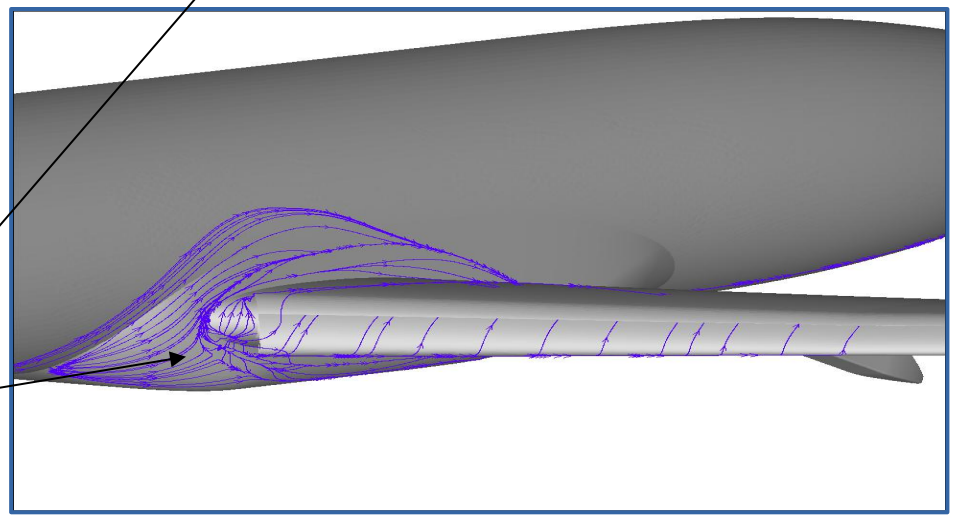
CASE 2a - WB - Oil flow

- WB - AOA = 18.58 deg



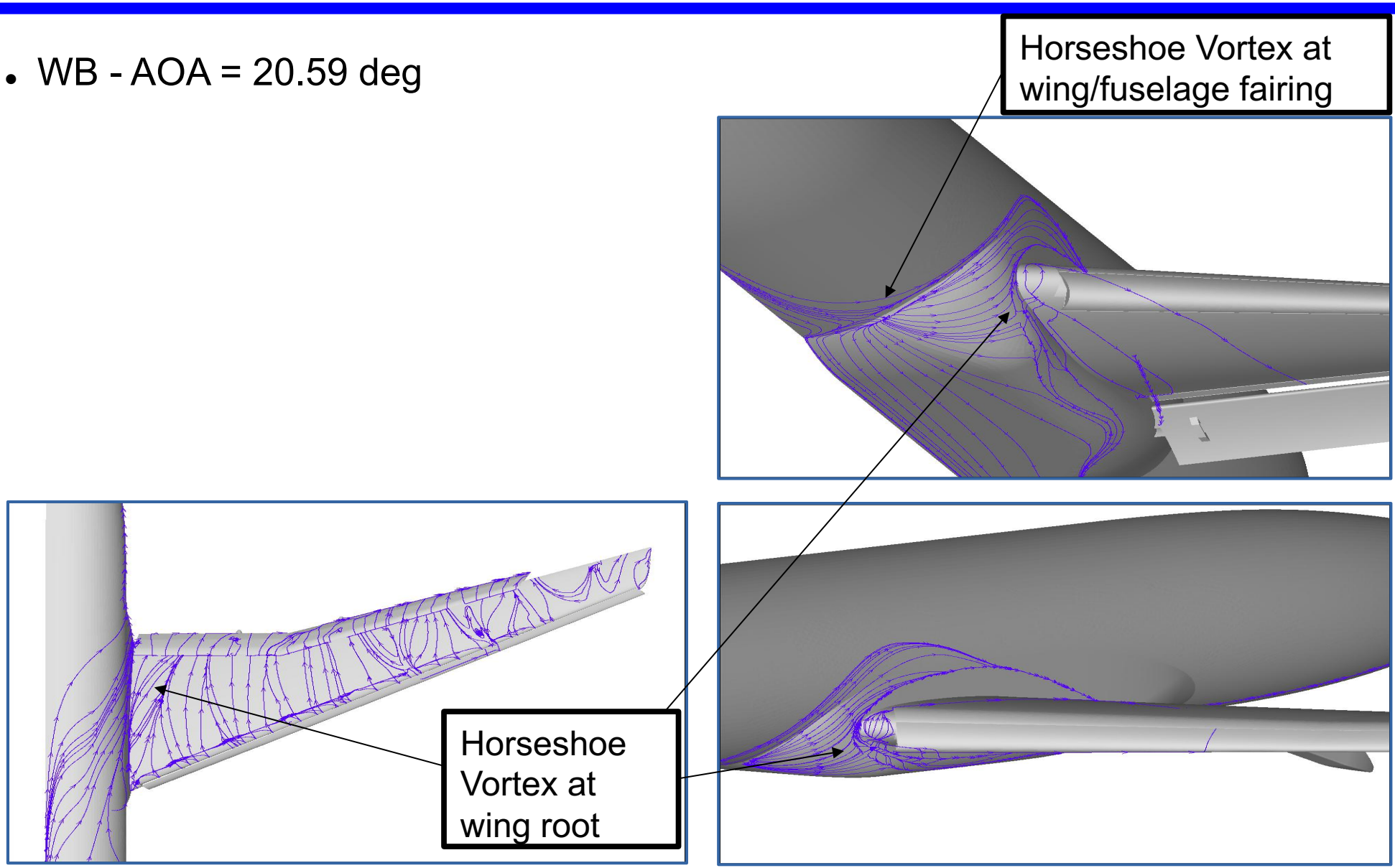






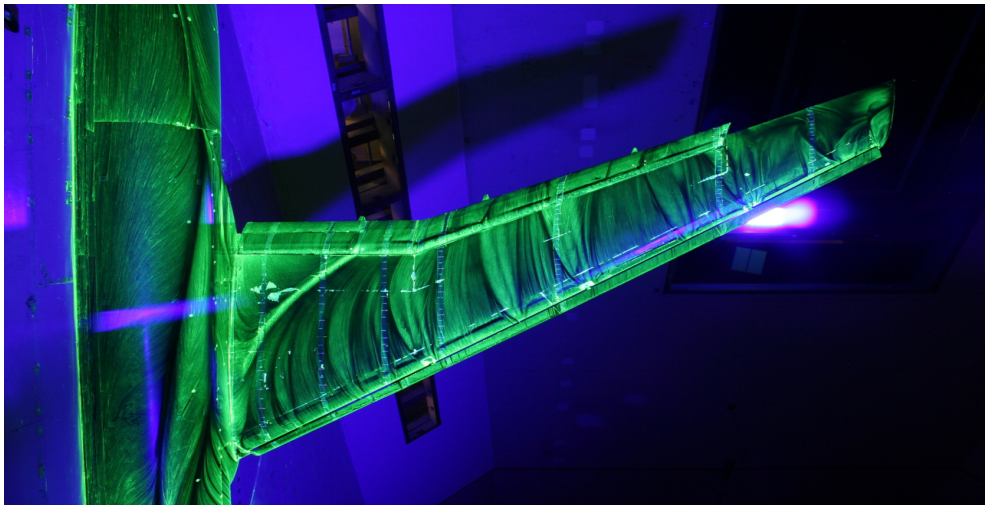
CASE 2a - WB - Oil flow

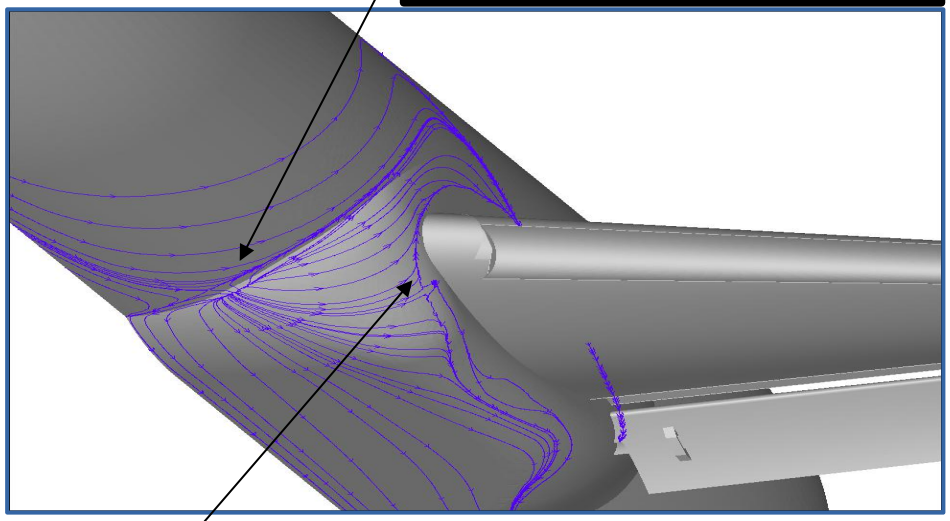
- WB - AOA = 20.59 deg

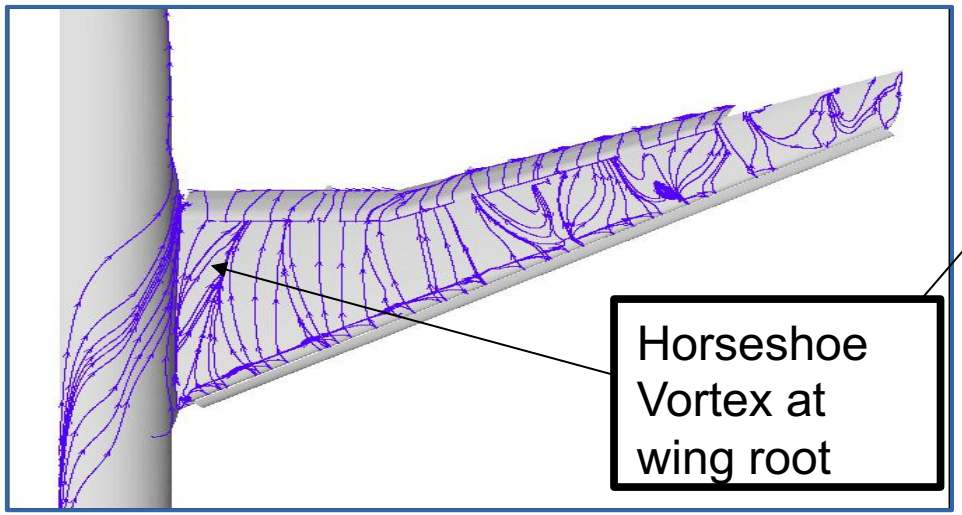


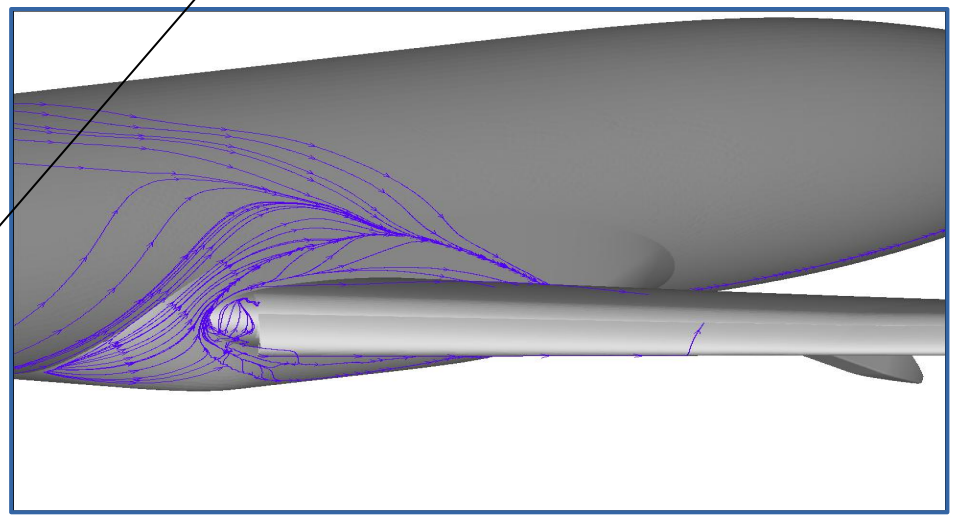
CASE 2a - WB - Oil flow

- WB - AOA = 21.57 deg



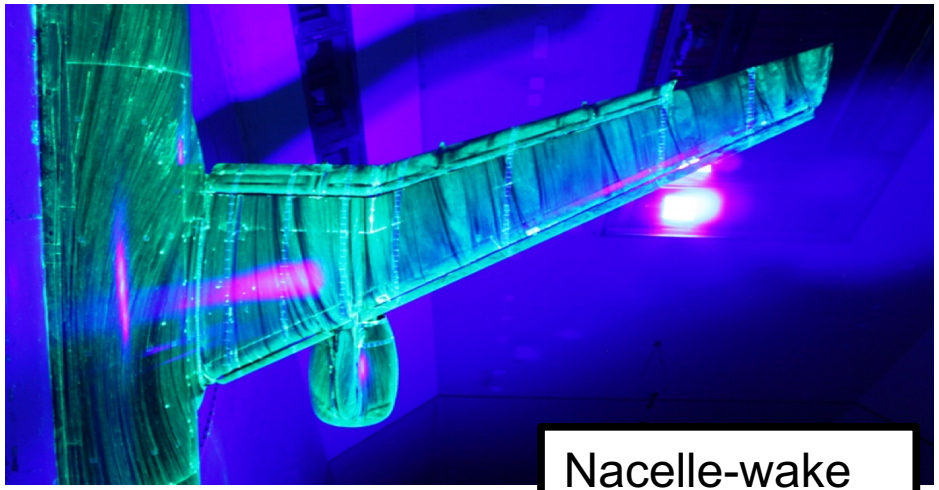


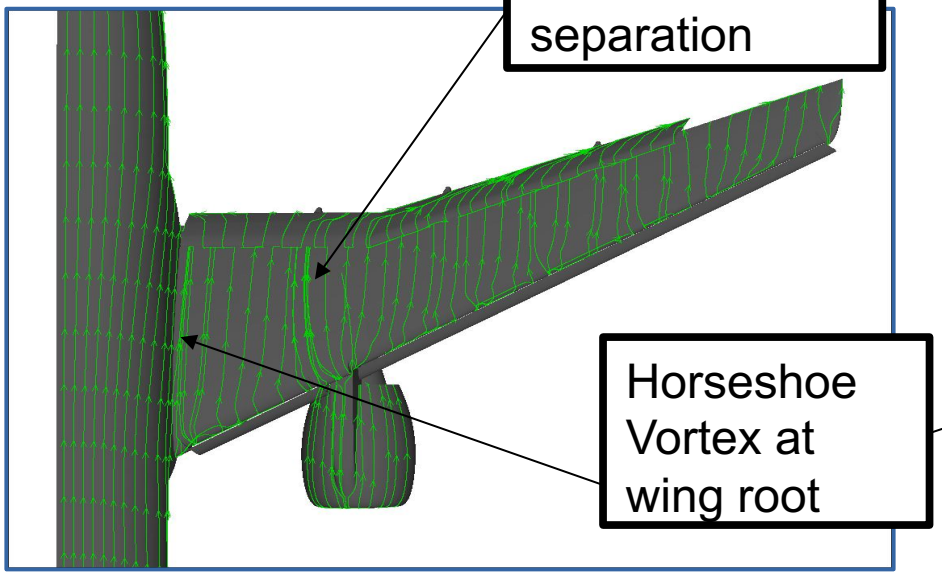


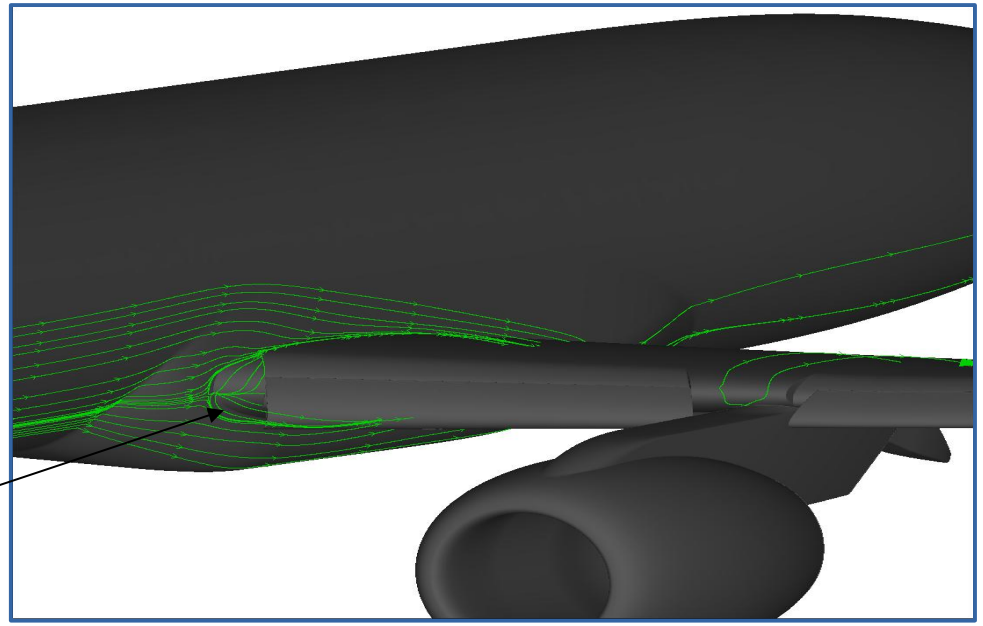


CASE 2c - WBPN - Oil flow

- WBPN - AOA = 4.36 deg

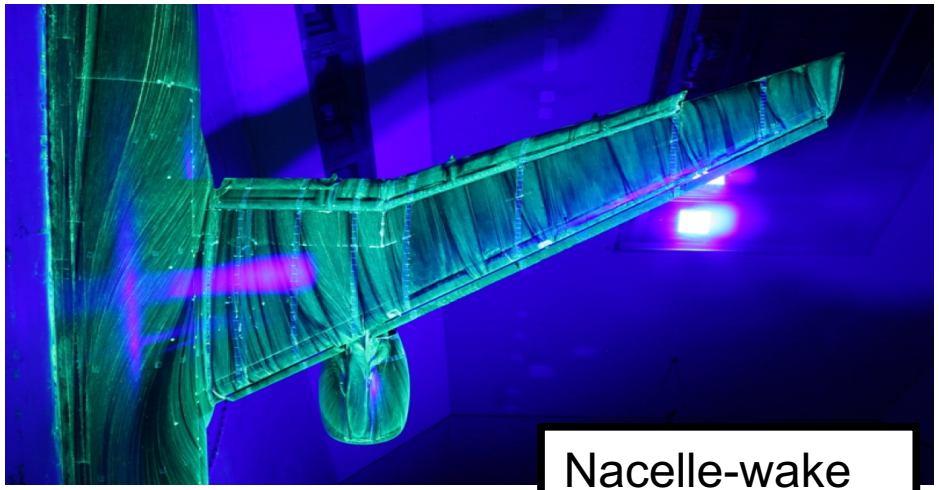


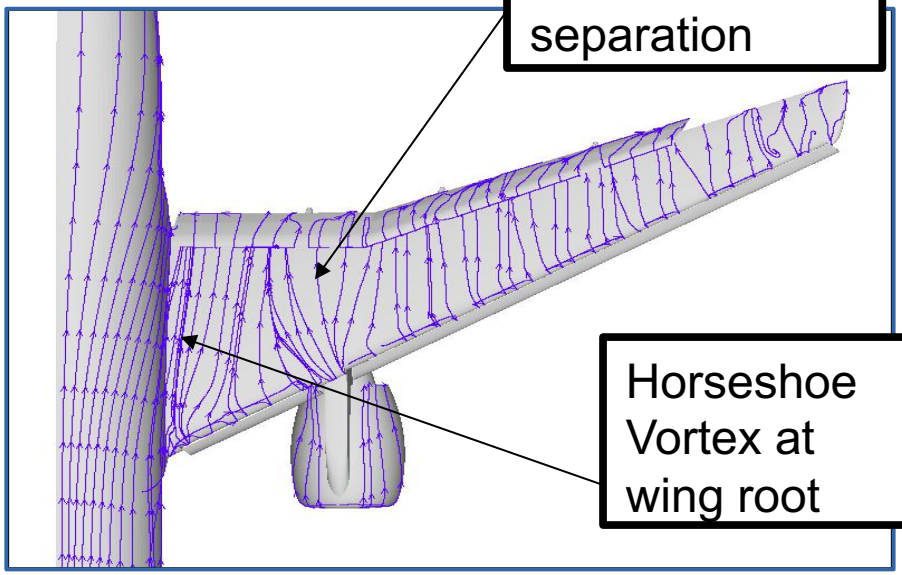


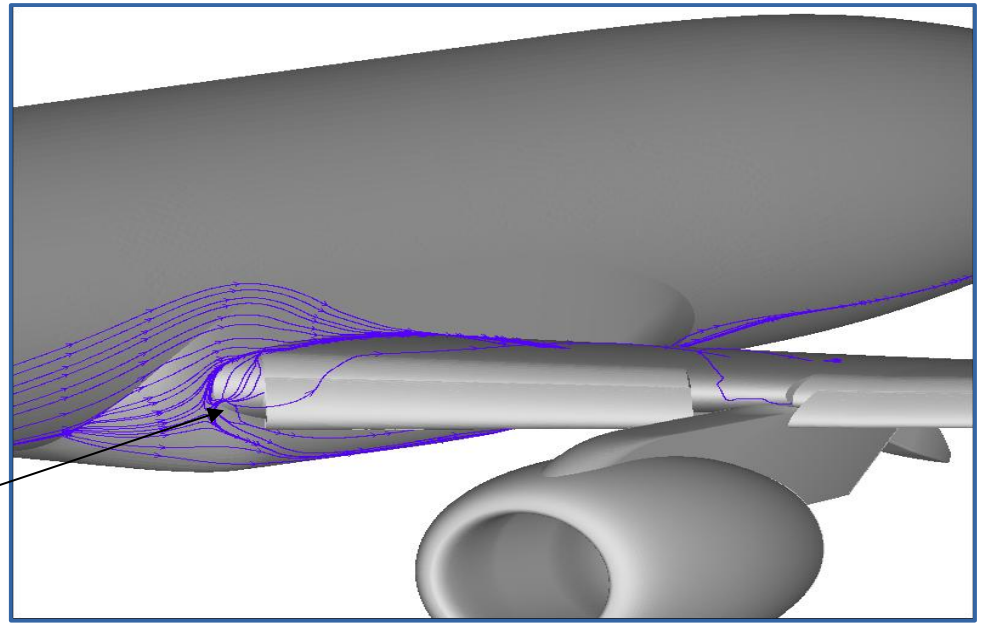


CASE 2c - WBPN - Oil flow

- WB - AOA = 10.48 deg

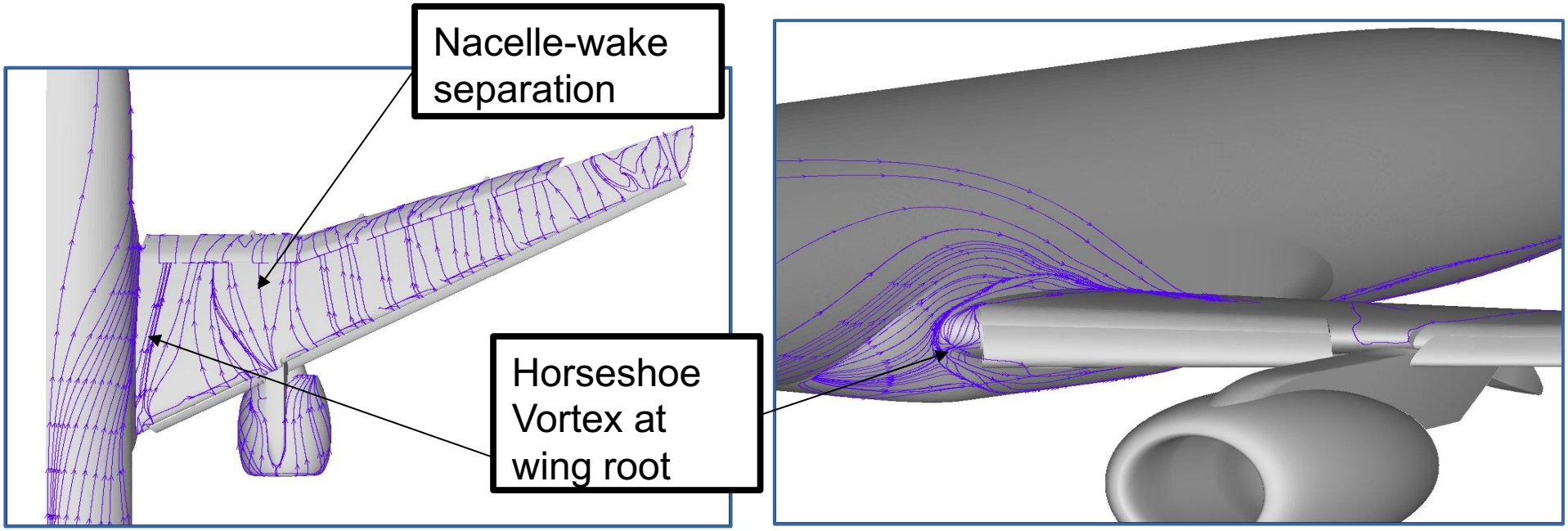






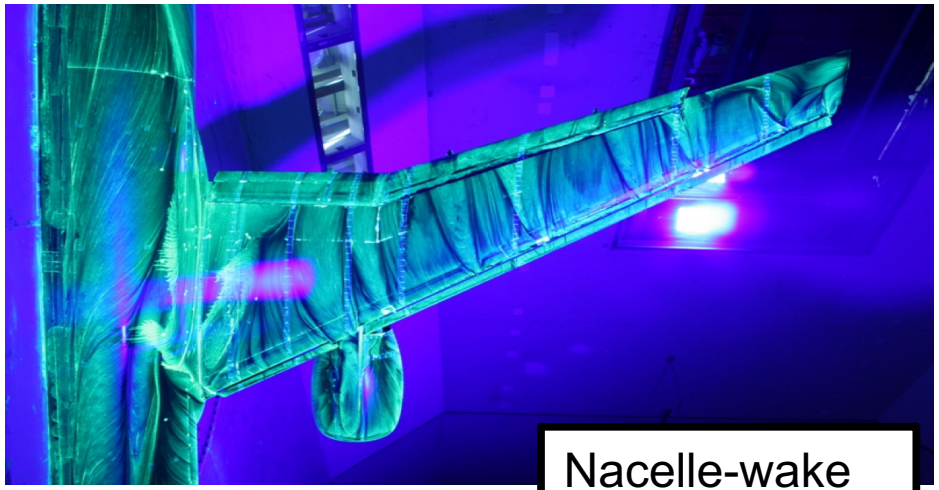
CASE 2c - WBPN - Oil flow

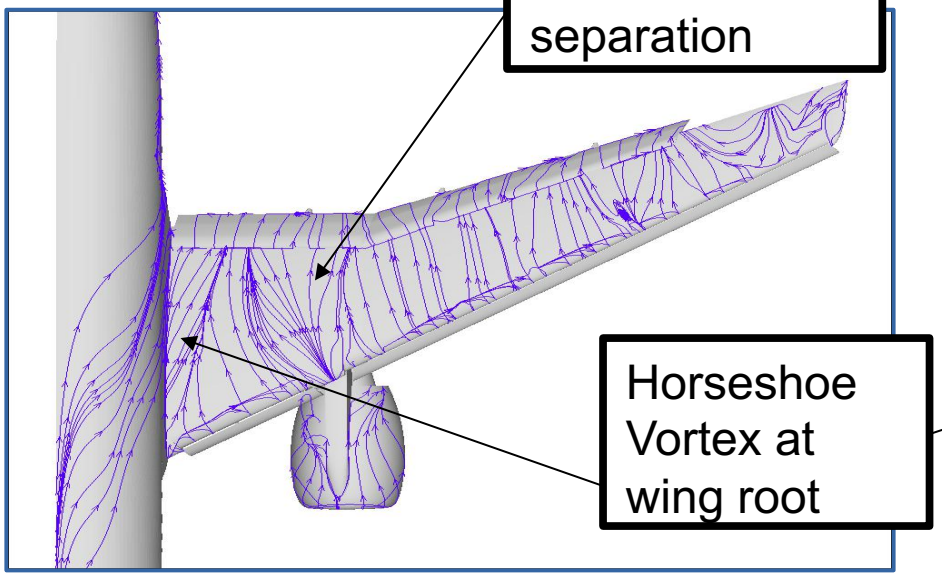
- WB - AOA = 14.54 deg

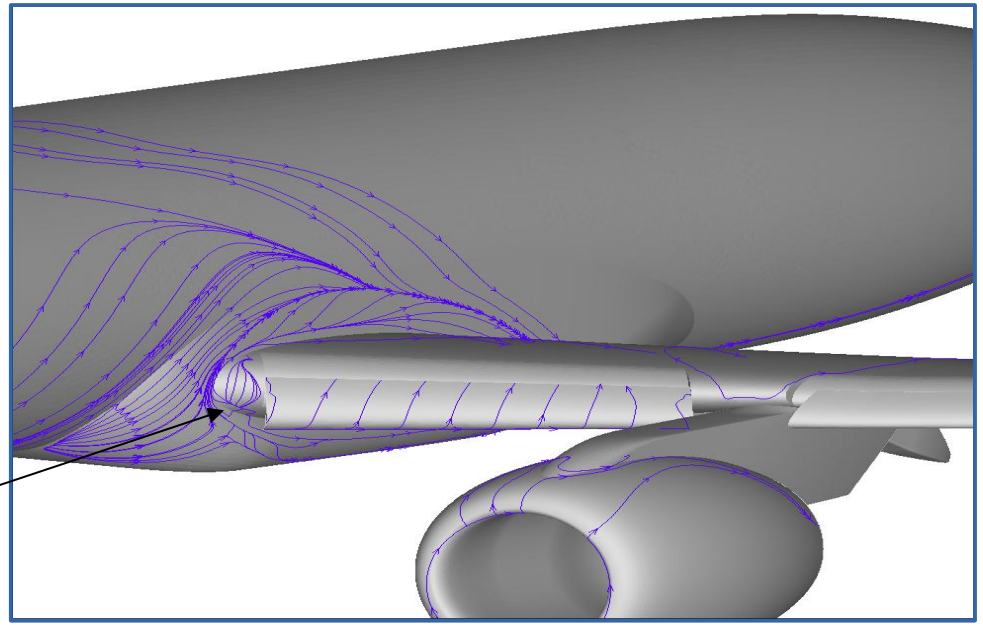


CASE 2c - WBPN - Oil flow

- WBPN - AOA = 18.58 deg

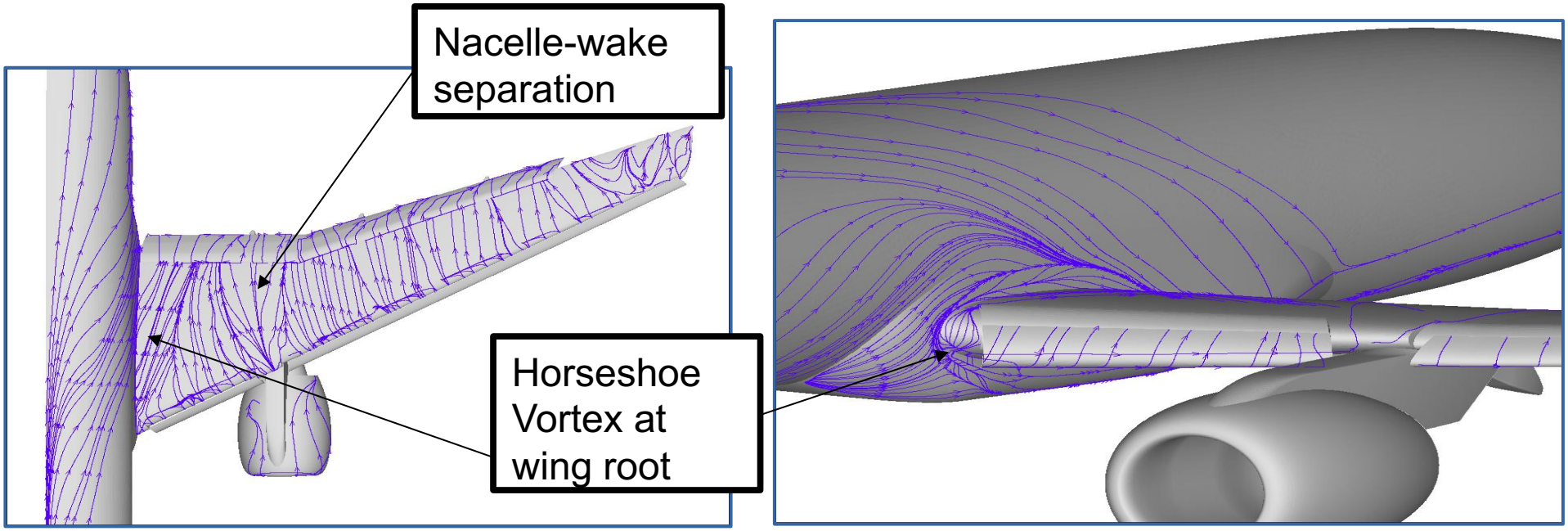






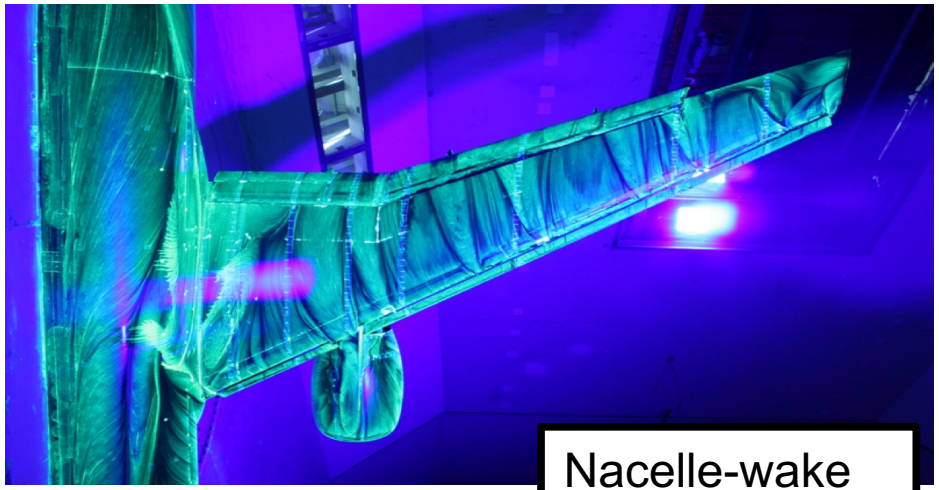
CASE 2c - WBPN - Oil flow

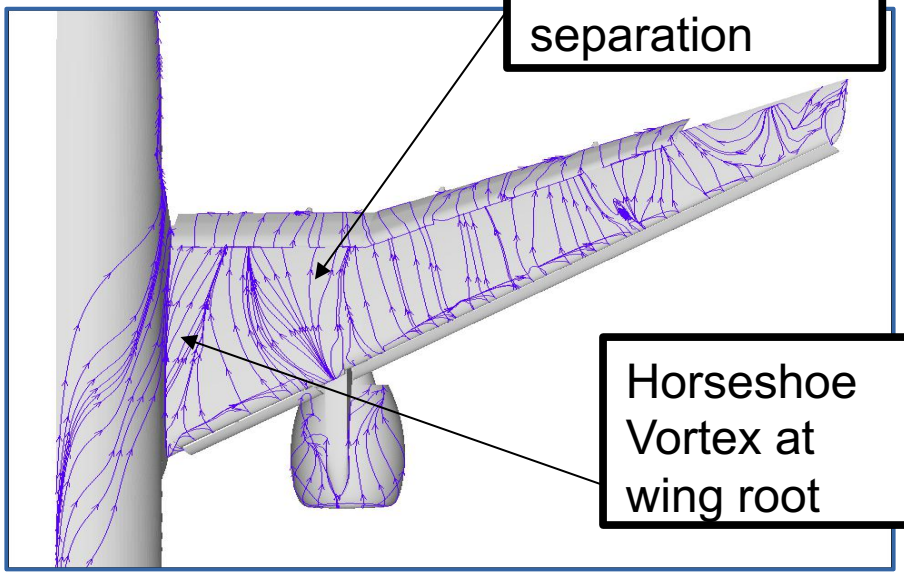
- WBPN - AOA = 20.59 deg

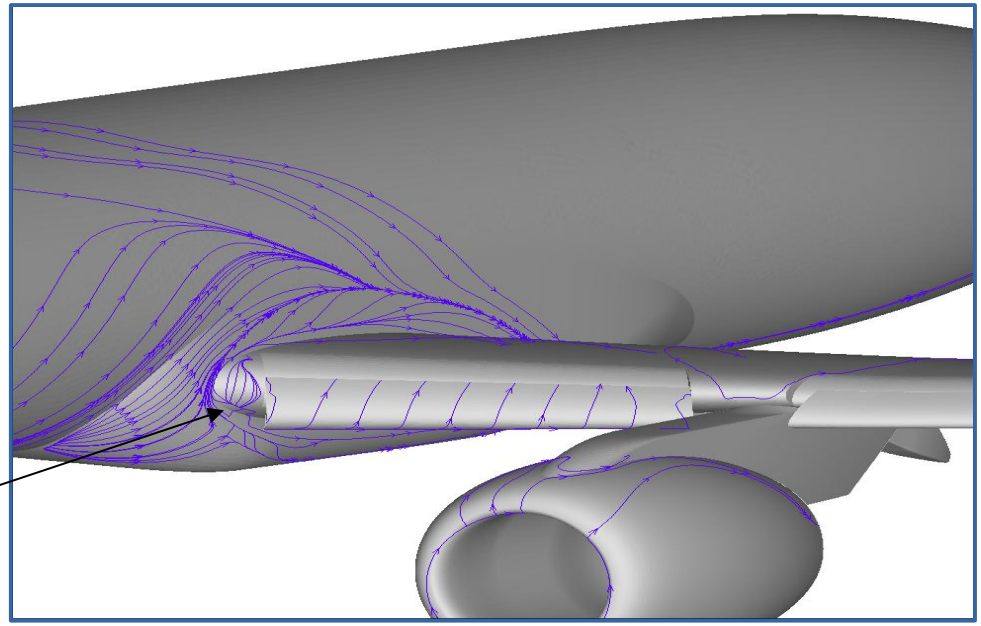


CASE 2c - WBPN - Oil flow

- WB - AOA = 21.57 deg







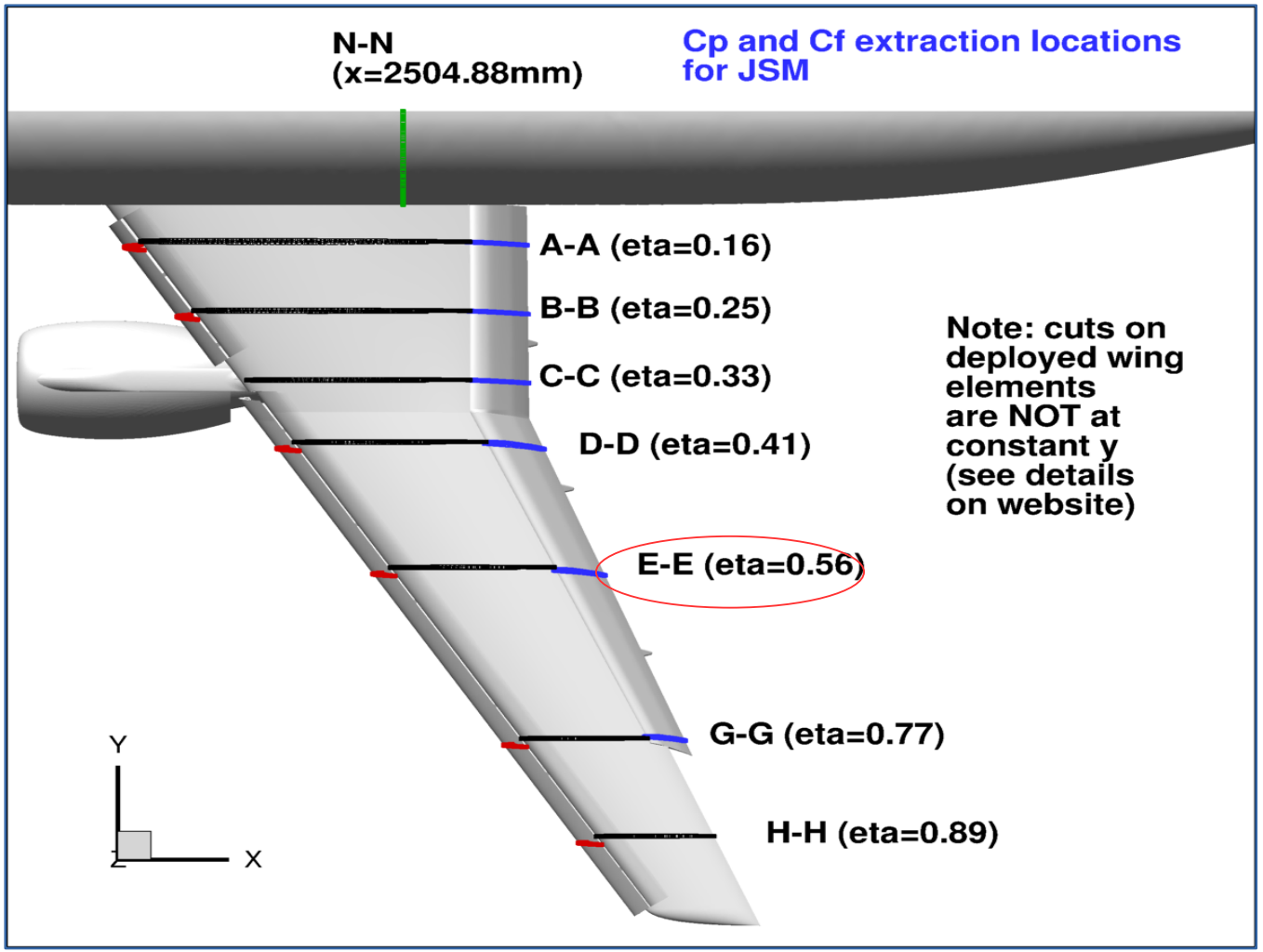
JAXA – WB and WBPN - Oil flow

- Case 2a WB configuration - Stall characteristics
  - Experimental results – The stall is triggered by the horseshoe vortex at the wing root.
  - Numerical results – The stall starts further outboard along the wing span.

- Case 2c WBPN configuration – Stall characteristics
  - Experimental results and numerical results show stall as consequence of wing root horseshoe vortex and nacelle-wake separation on inboard wing panel.
  - These flow features prevent the growth of wing load at the inboard wing panel region.

CASE 2c - WBPN
Comparison of CP distribution

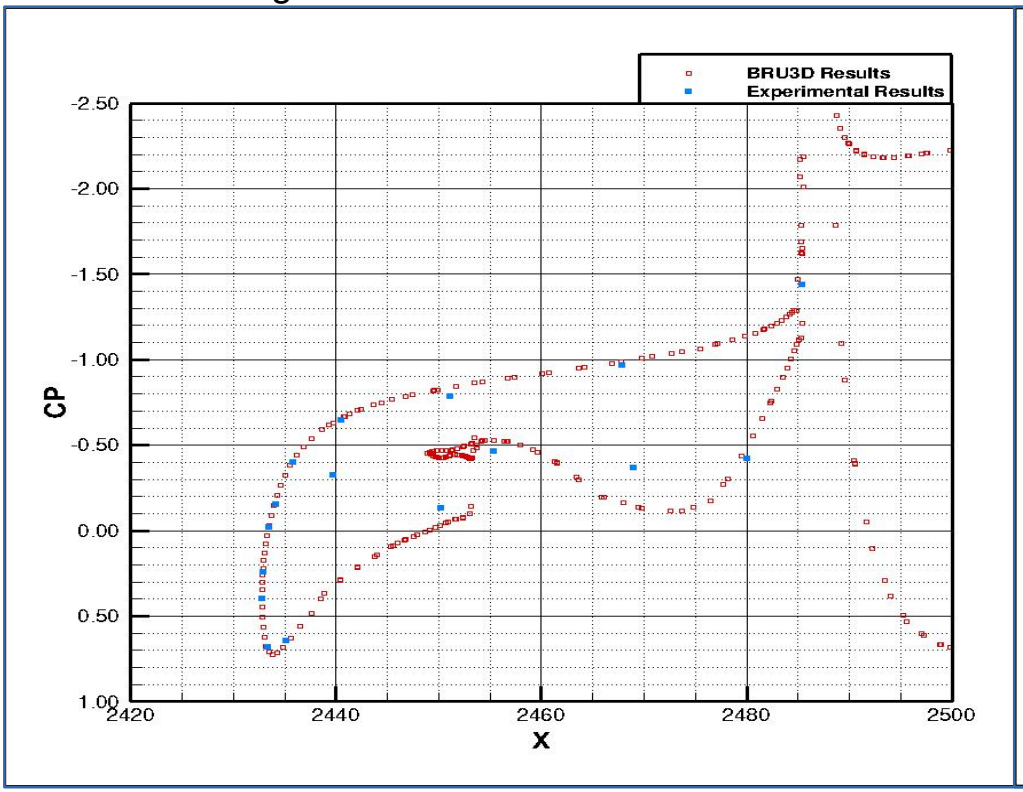
- Postprocessing: Surface Data Extraction for JSM (Case 2)



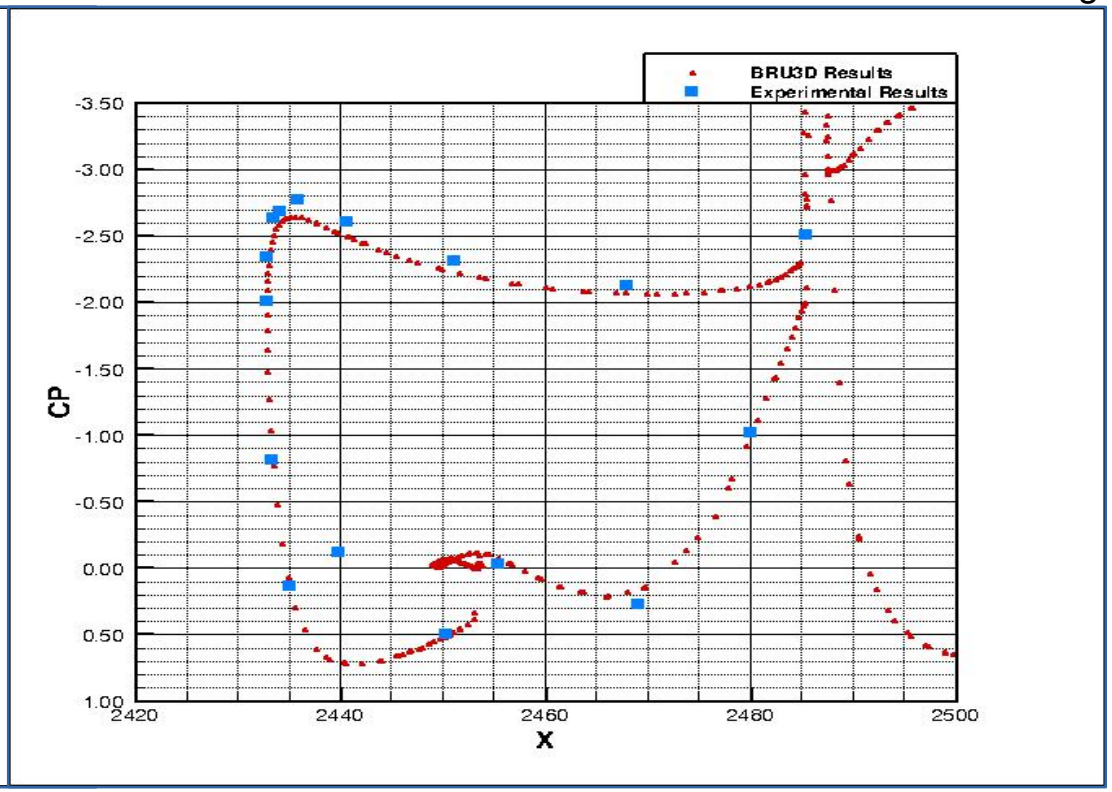
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – SLAT E - E

AOA = 4.36 deg



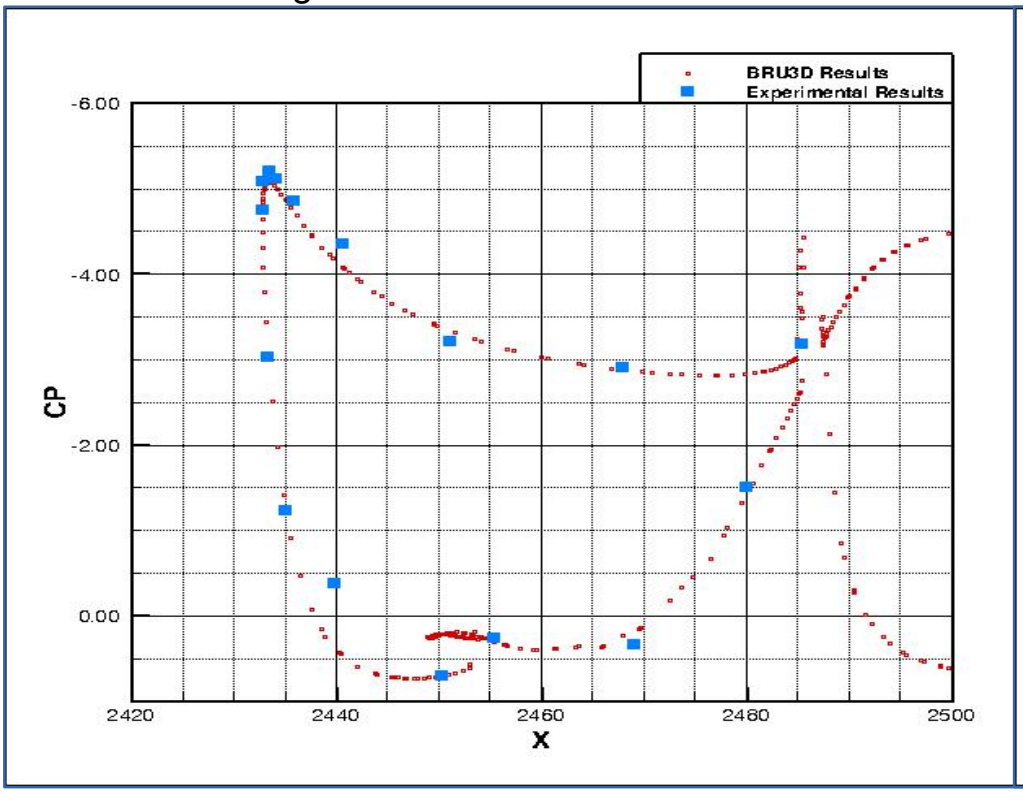
AOA = 10.47 deg



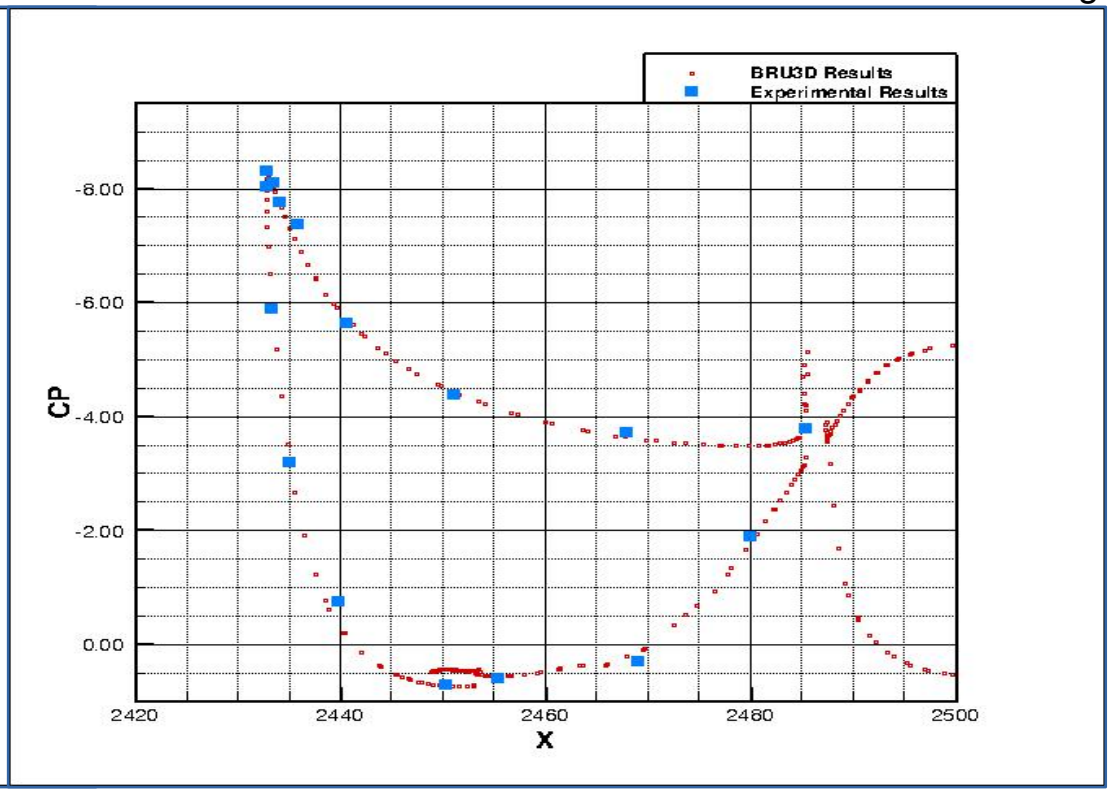
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – SLAT E - E

AOA = 14.54 deg



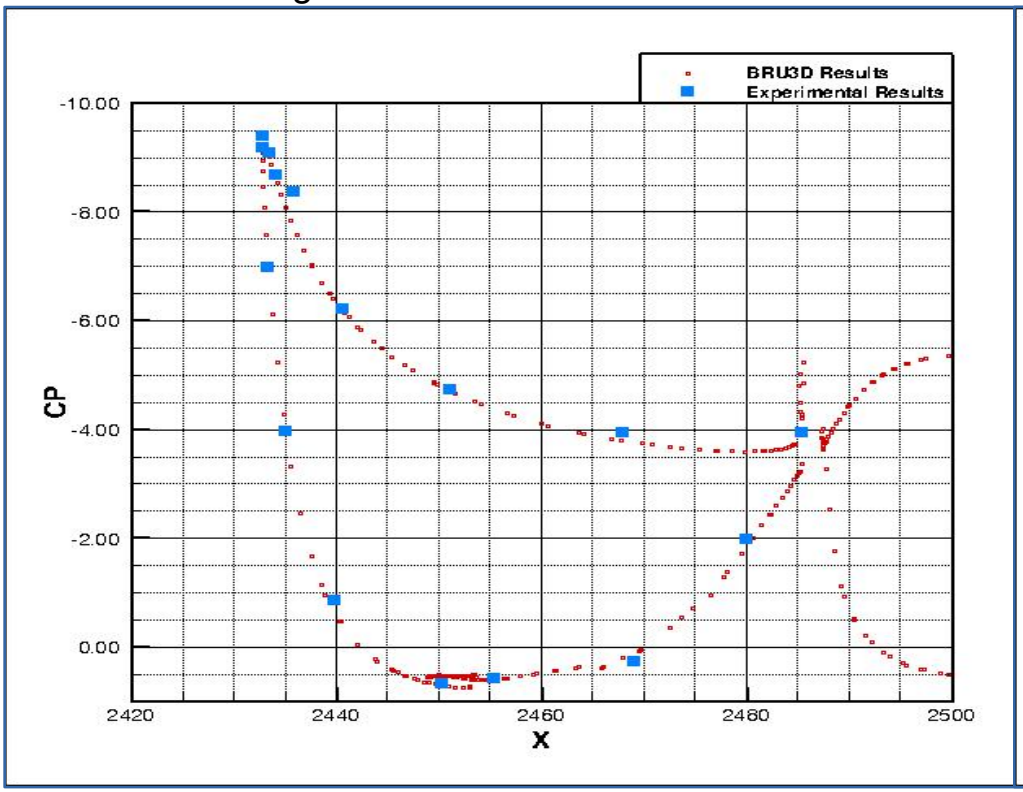
AOA = 18.58 deg



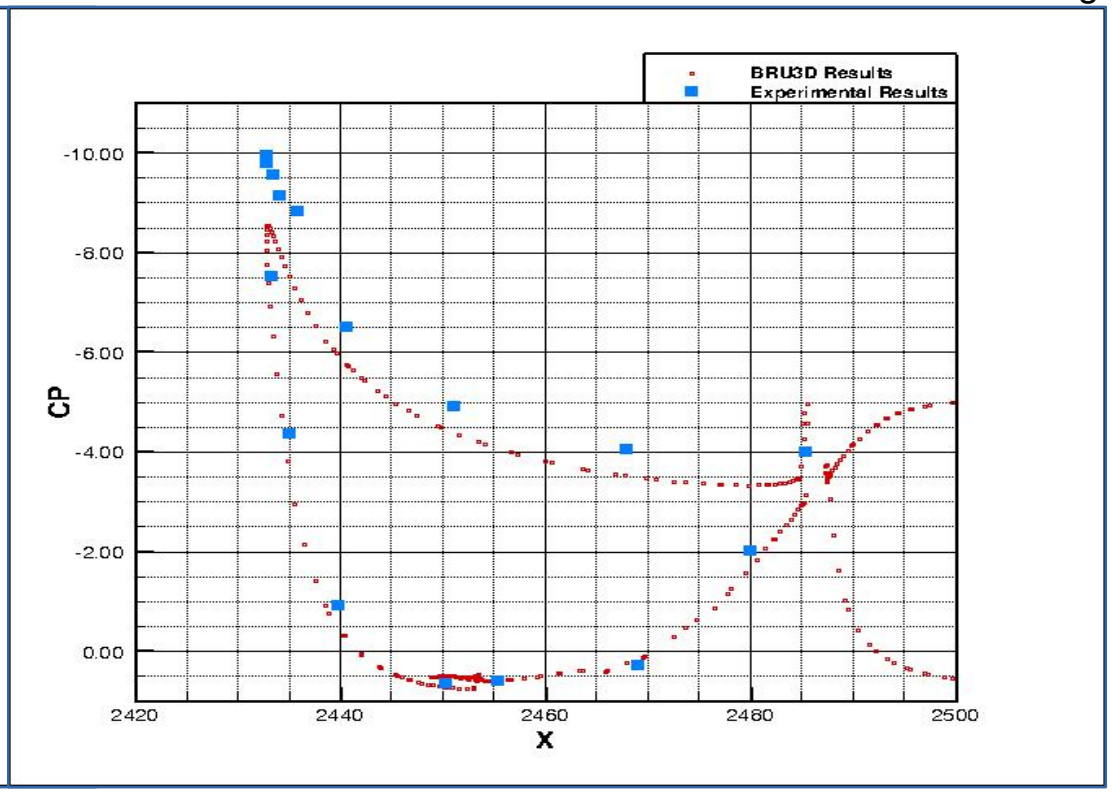
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – SLAT E - E

AOA = 20.57 deg



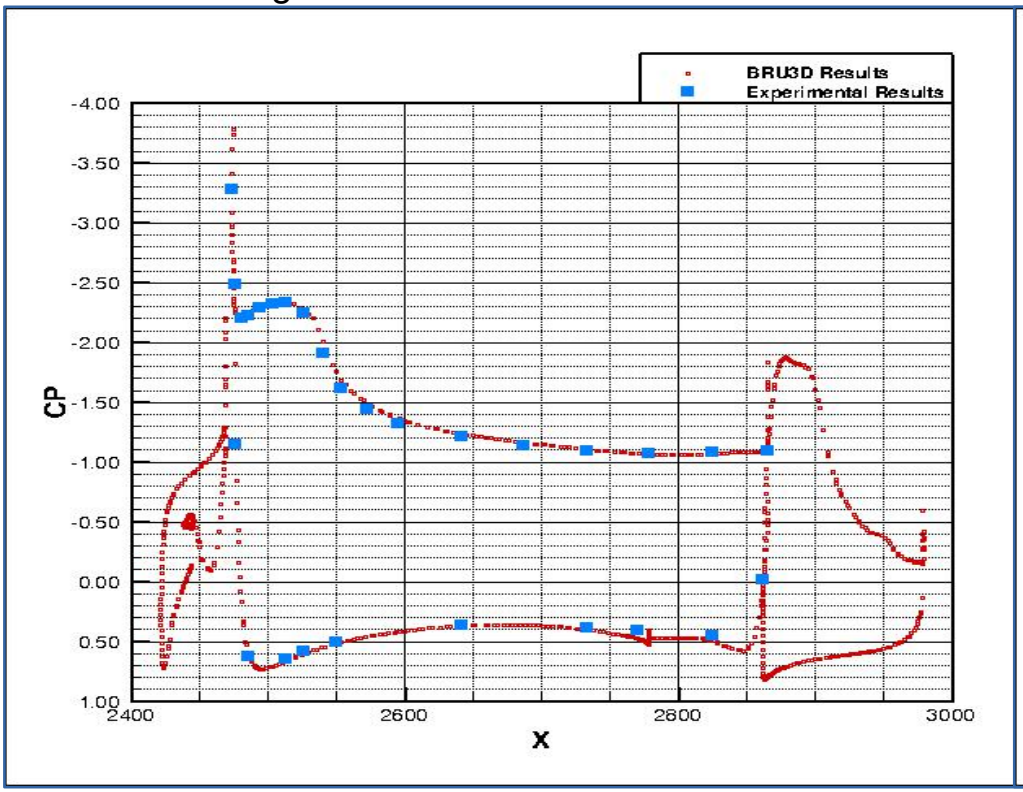
AOA = 21.59 deg



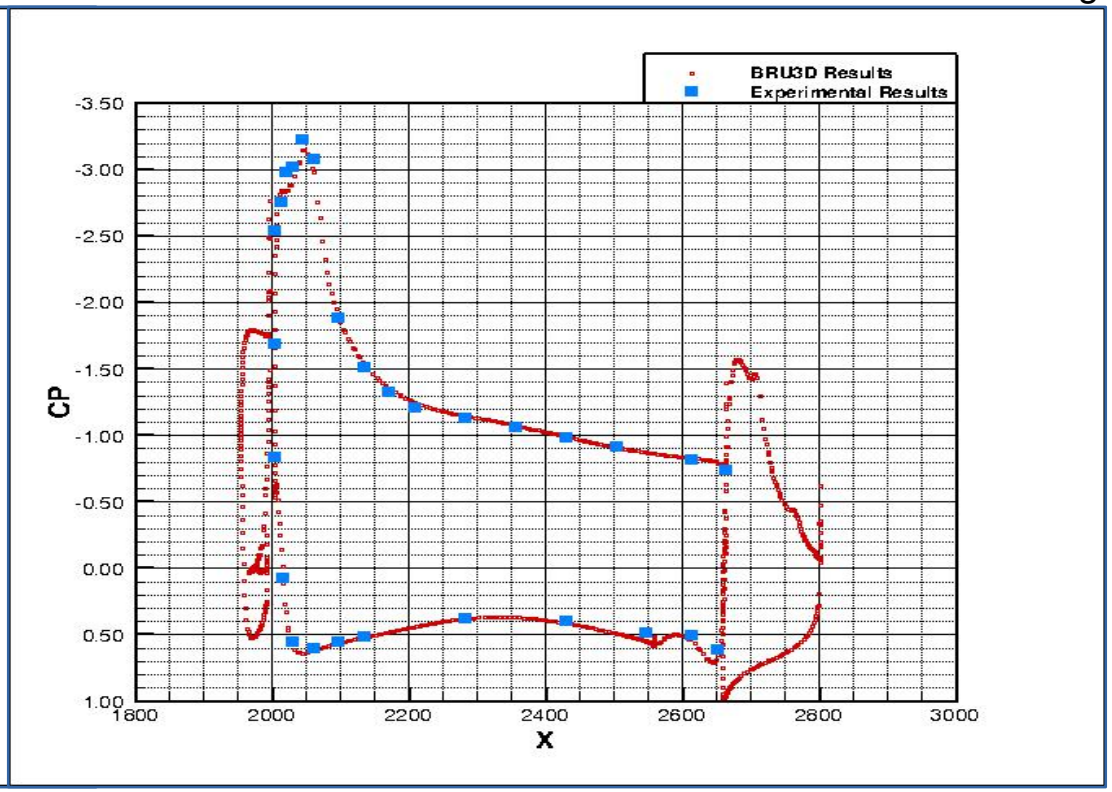
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – MAIN ELEMENT E - E

AOA = 4.36 deg



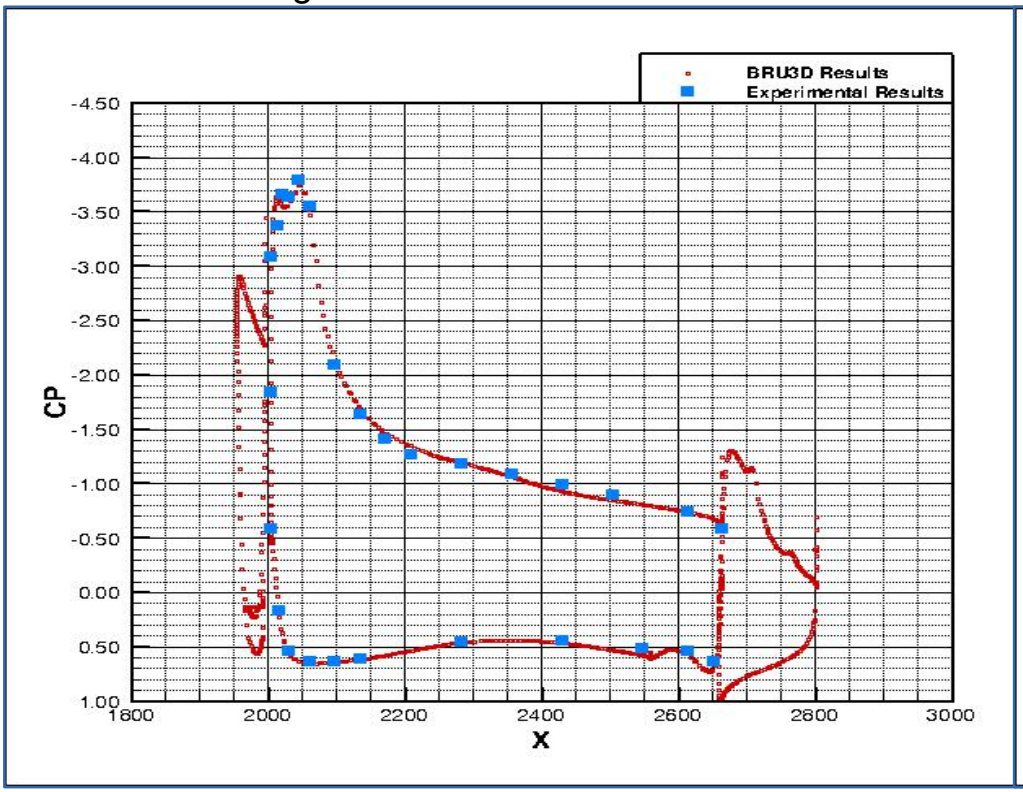
AOA = 10.47 deg



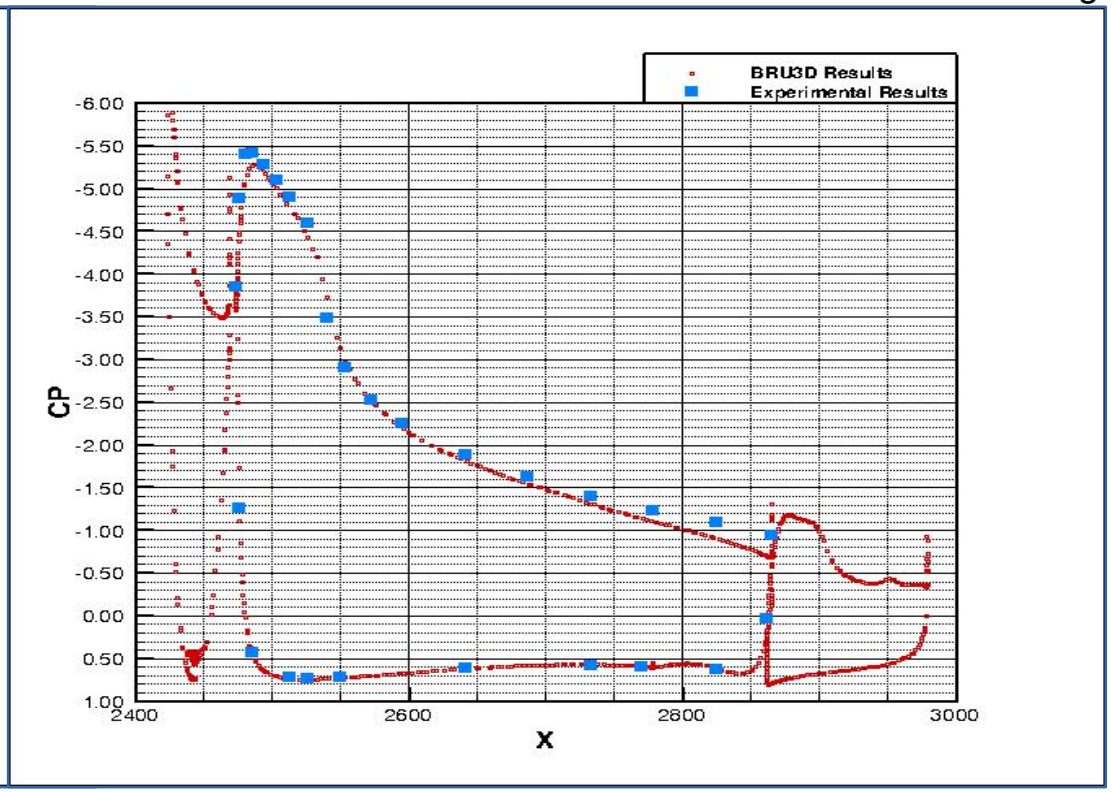
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – MAIN ELEMENT E - E

AOA = 14.54 deg



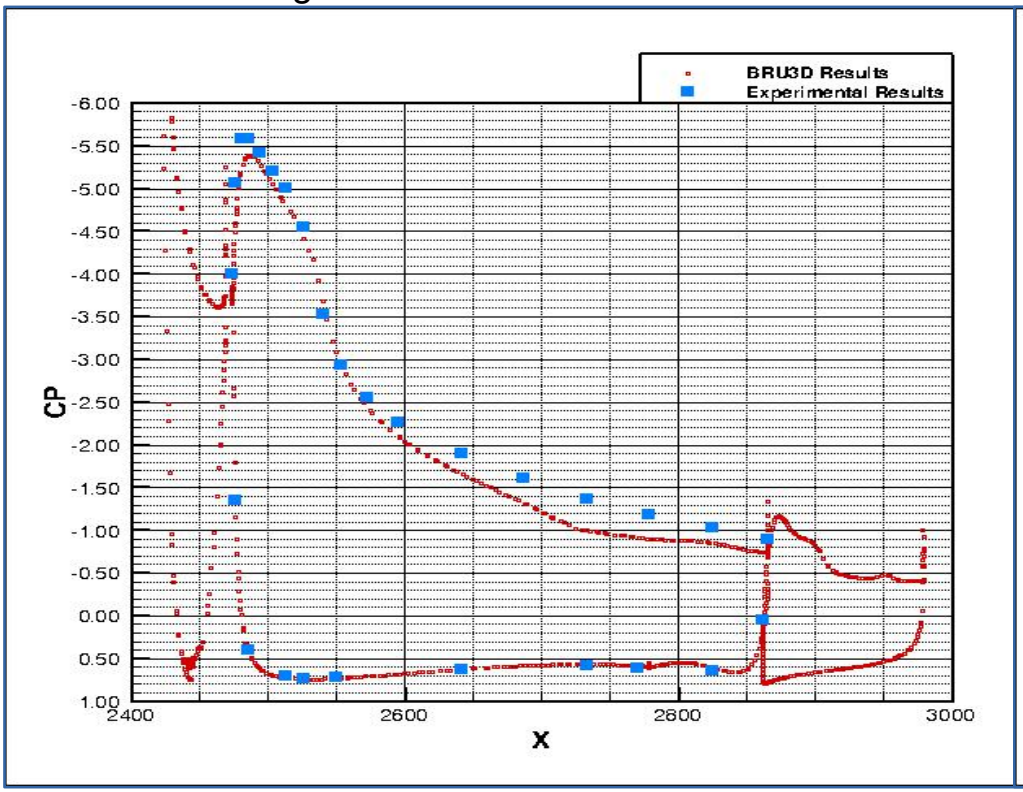
AOA = 18.58 deg



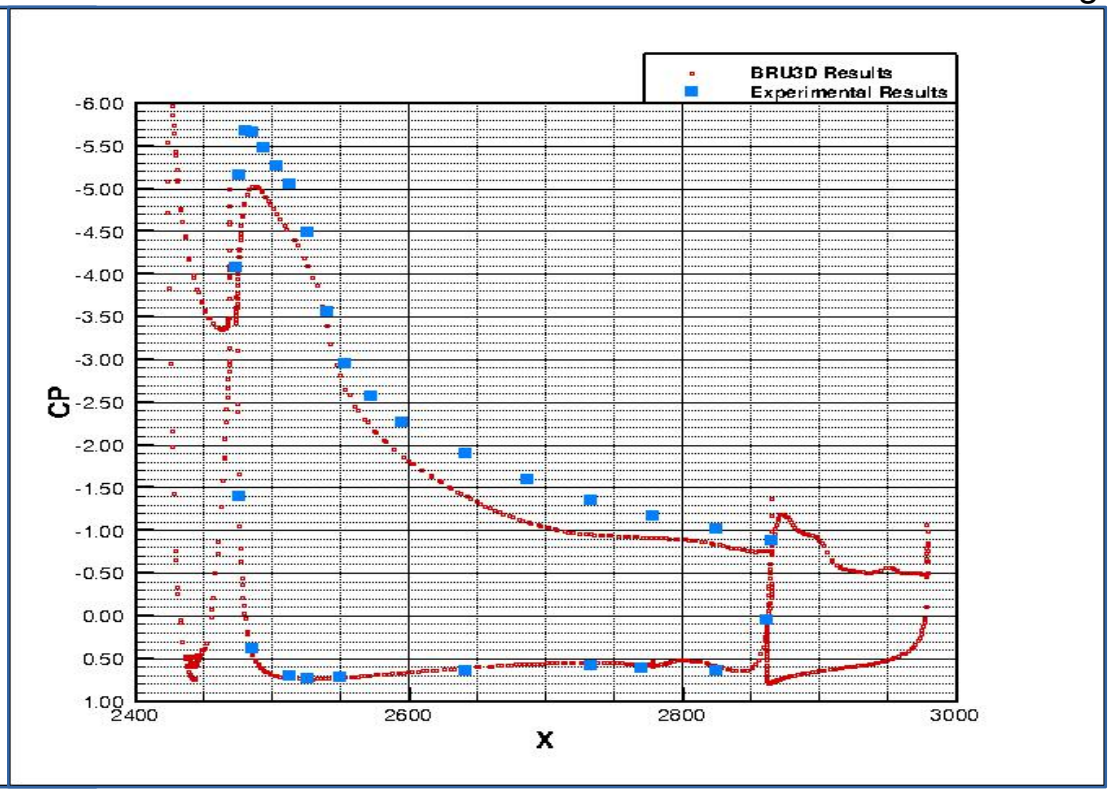
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – MAIN ELEMENT E - E

AOA = 20.57 deg



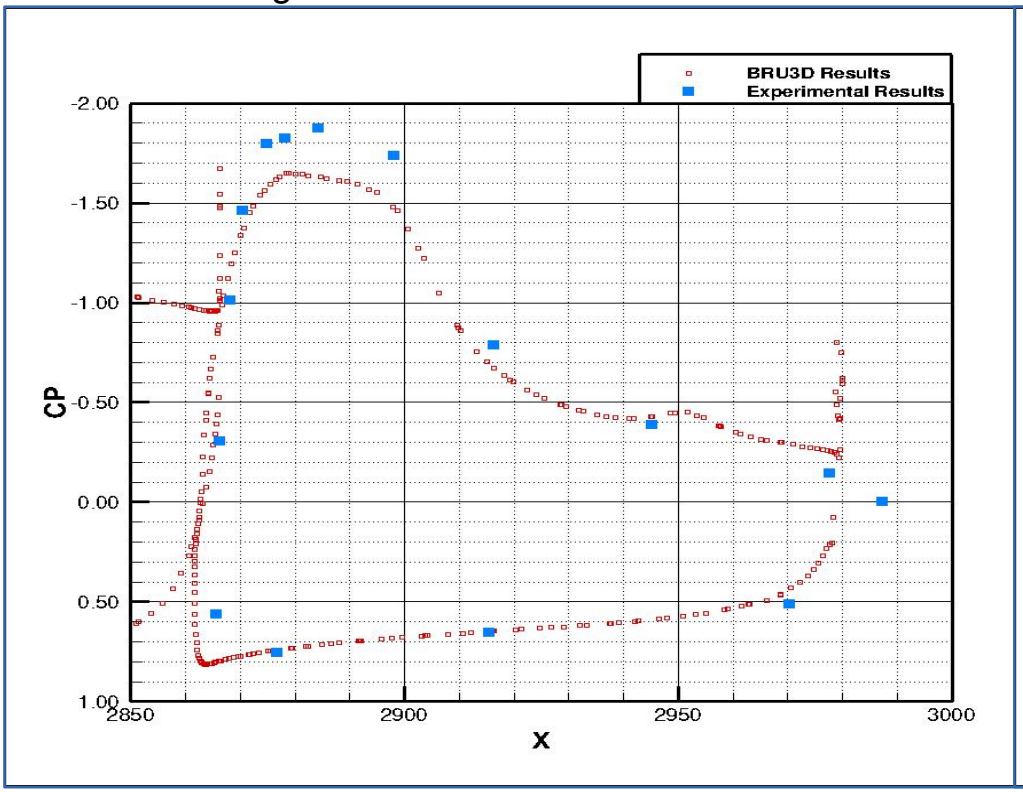
AOA = 21.59 deg



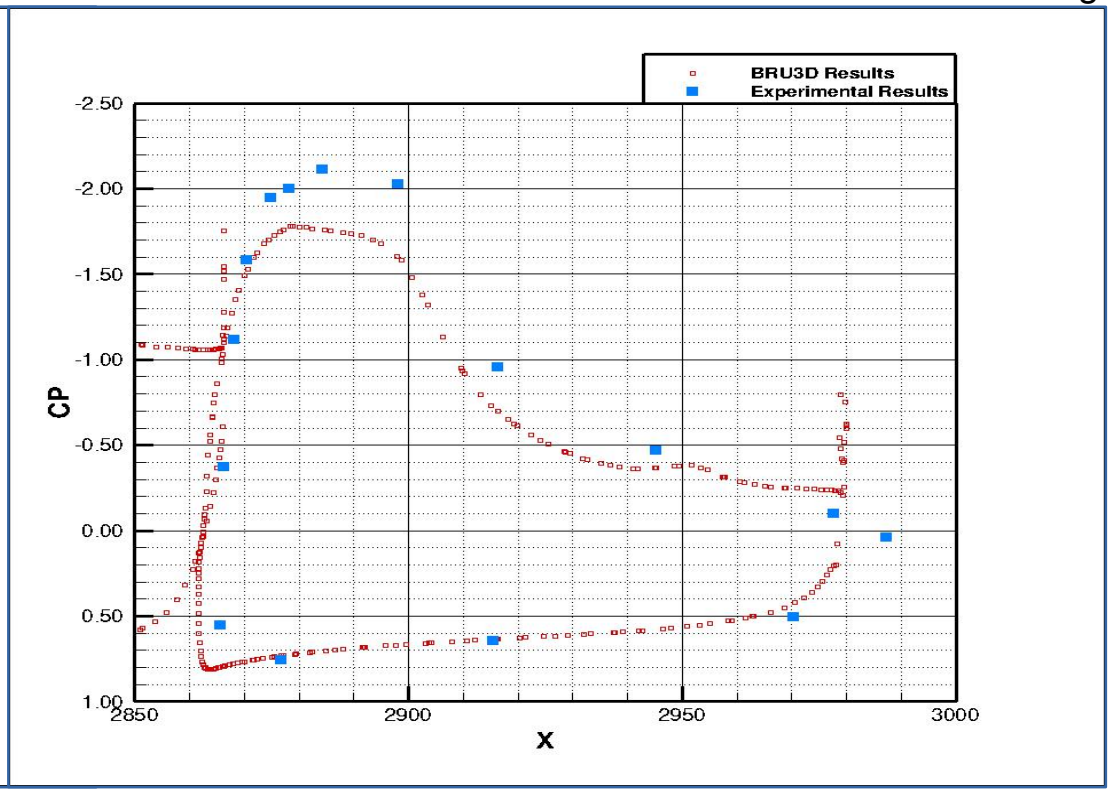
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – FLAP E - E

AOA = 4.36 deg



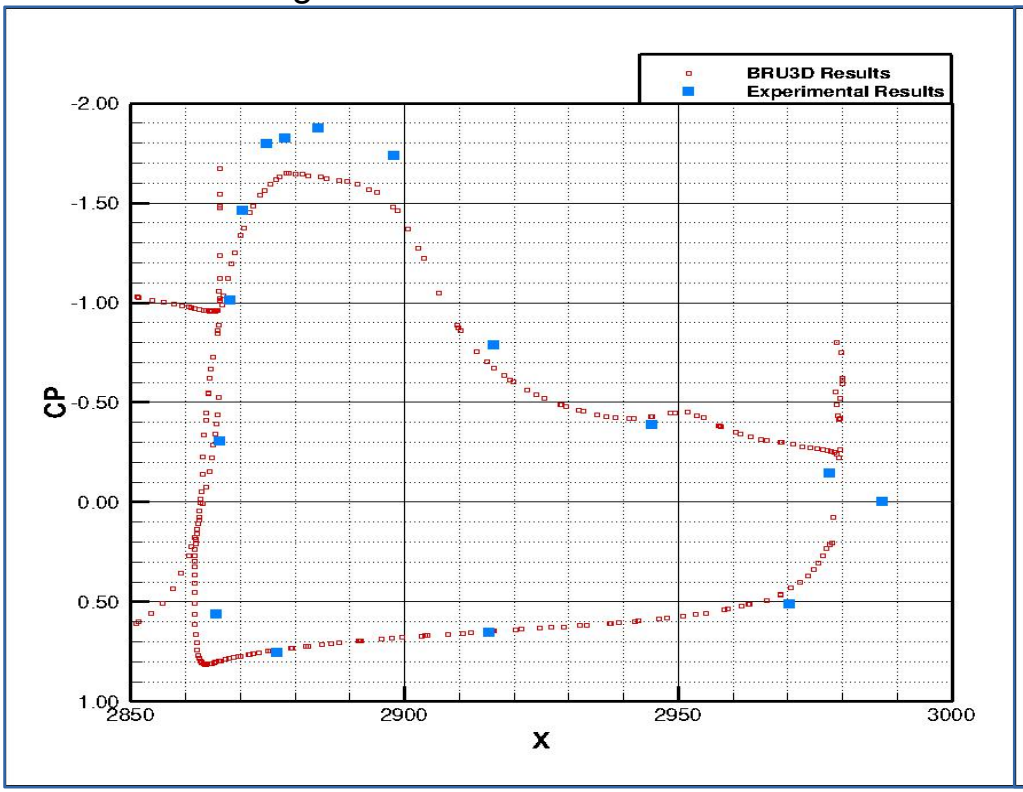
AOA = 10.47 deg



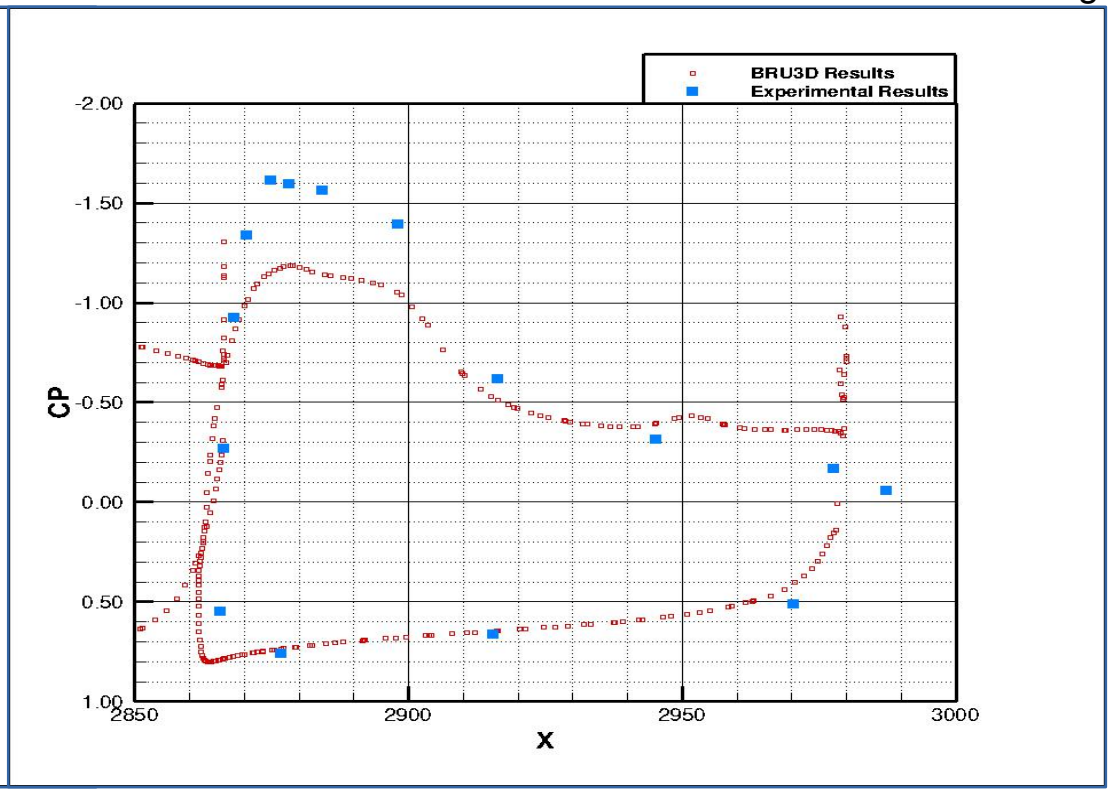
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – FLAP E - E

AOA = 14.54 deg



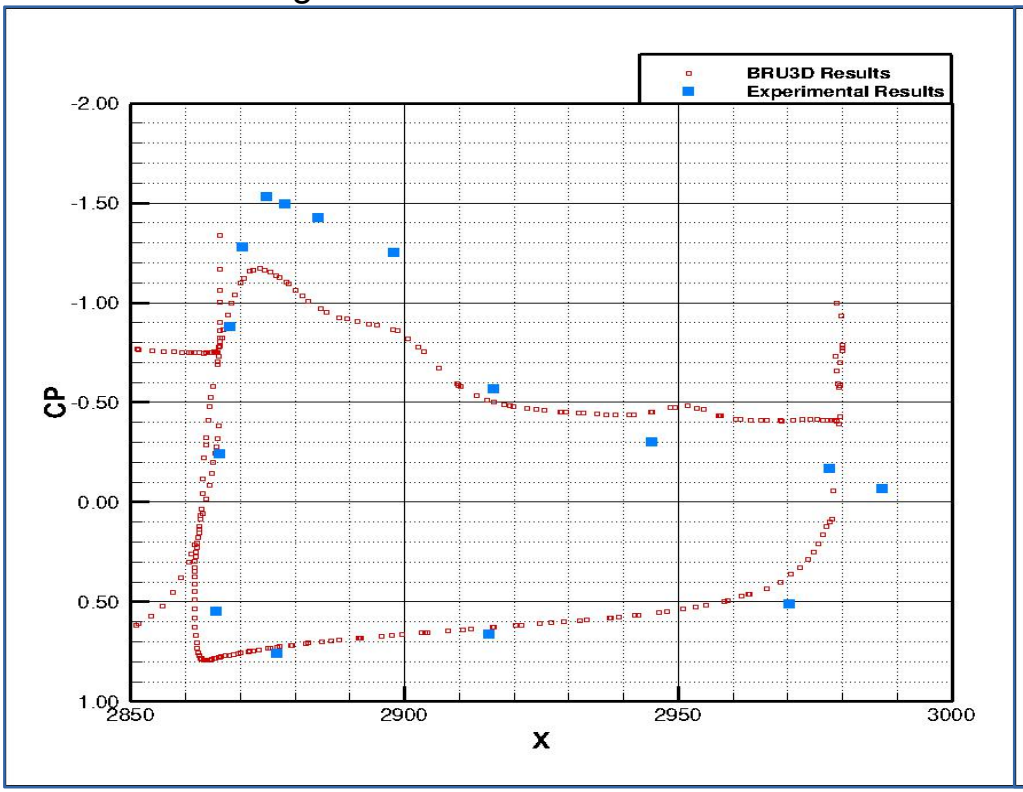
AOA = 18.58 deg



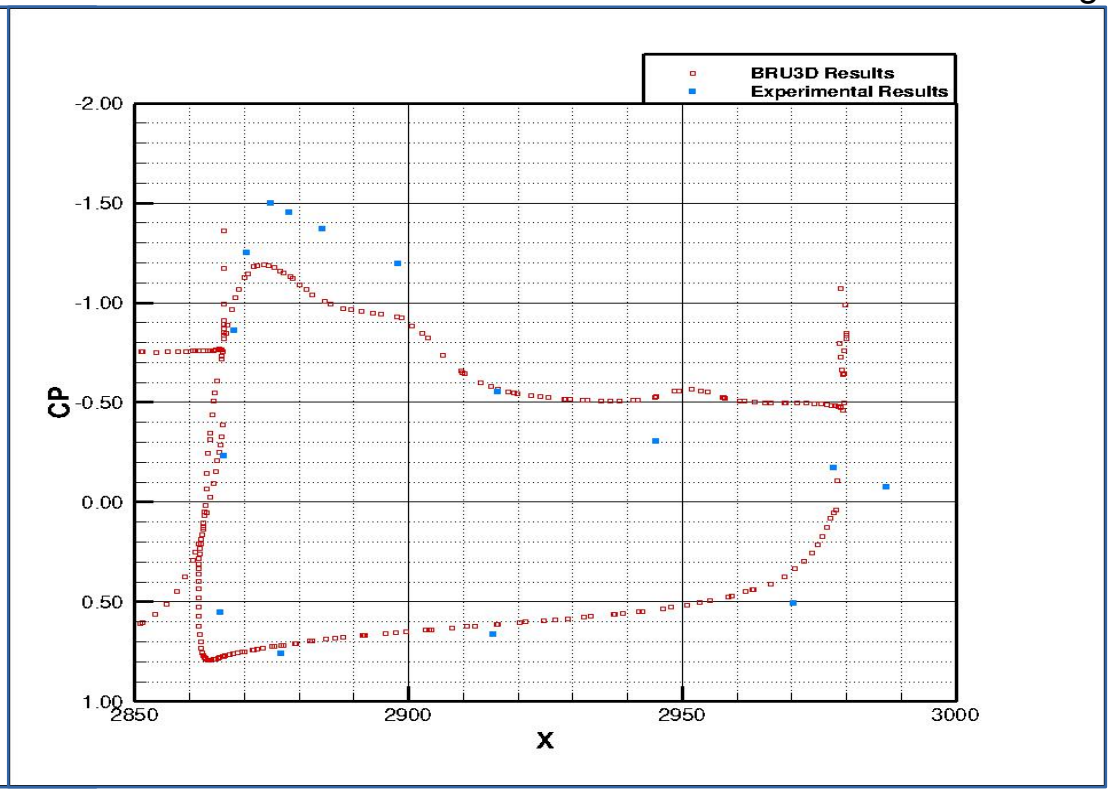
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – FLAP E - E

AOA = 20.57 deg



AOA = 21.59 deg



Concluding Remarks

- **Case 1a**
  - The flow at inboard flap reattaches as the AOA increases from 8 to 16 deg.
  - On the other hand, the flow at outboard flap remains separated.
  - The largest variations in Cp distribution, as the mesh is refined, occur in the outboard flap and at the aileron region for AOA 16 deg.
  - The differences are related to flow separation.
  - The mesh refinement modifies the peak of minimum Cp along the main element.

Concluding Remarks

- Case 2a: WB configuration - Stall characteristics
  - Experimental results – Stall is triggered by the horseshoe vortex at the wing root.
  - Numerical results – Stall starts further outboard along the wing span.

- Case 2c: WBPN configuration – Stall characteristics
  - Experimental results and numerical results show stall as consequence of wing root horseshoe vortex and nacelle-wake separation on inboard wing panel.
  - These flow features prevent the growth of the wing load at the inboard wing panel region.

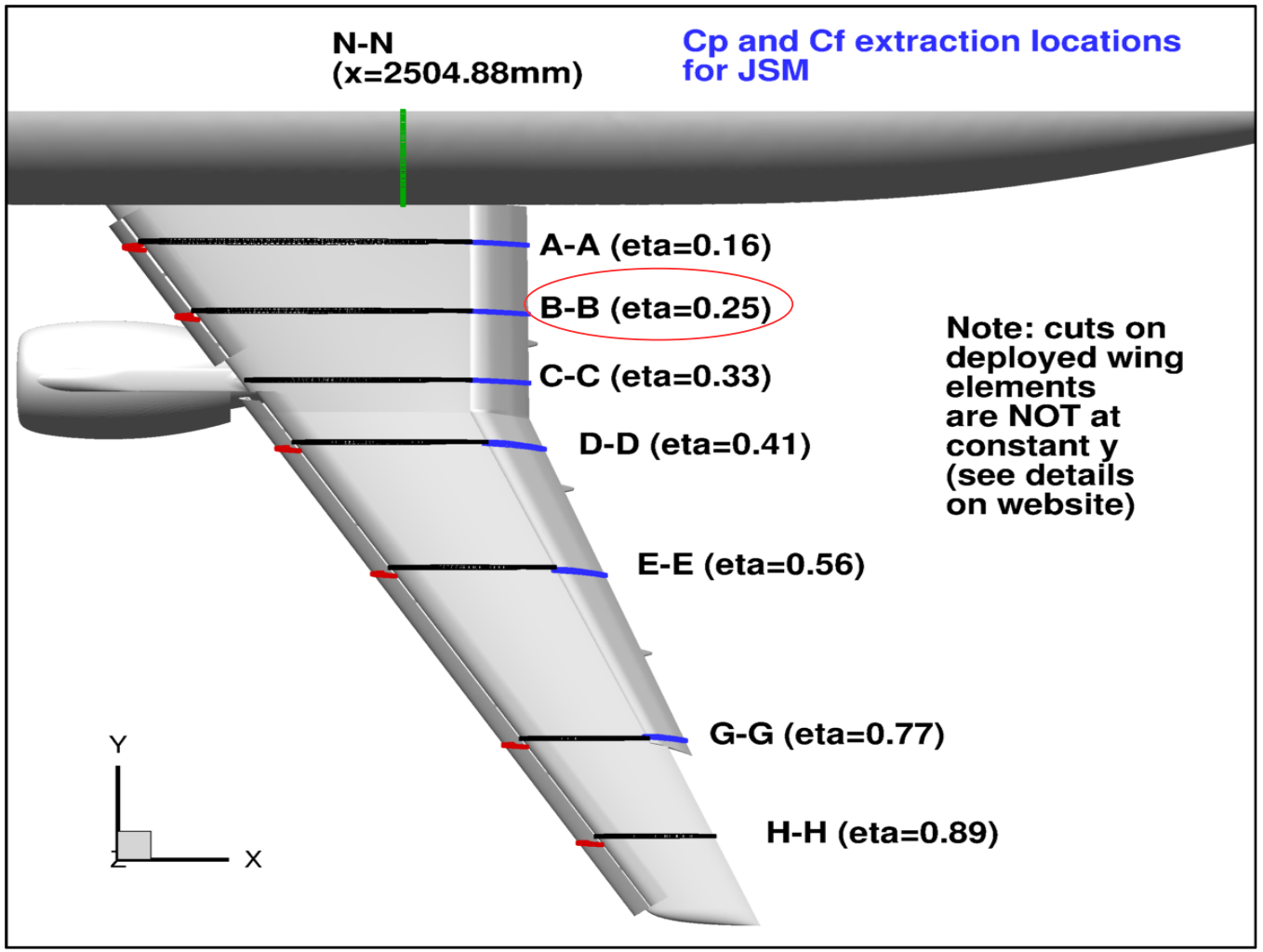
- For Cases 2a (WB) and 2c (WBPN), the comparison between experimental results and numerical results show a good agreement when the flow is attached.

Thank you !

Additional Slides

CASE 2a - WB
Comparison of CP distribution

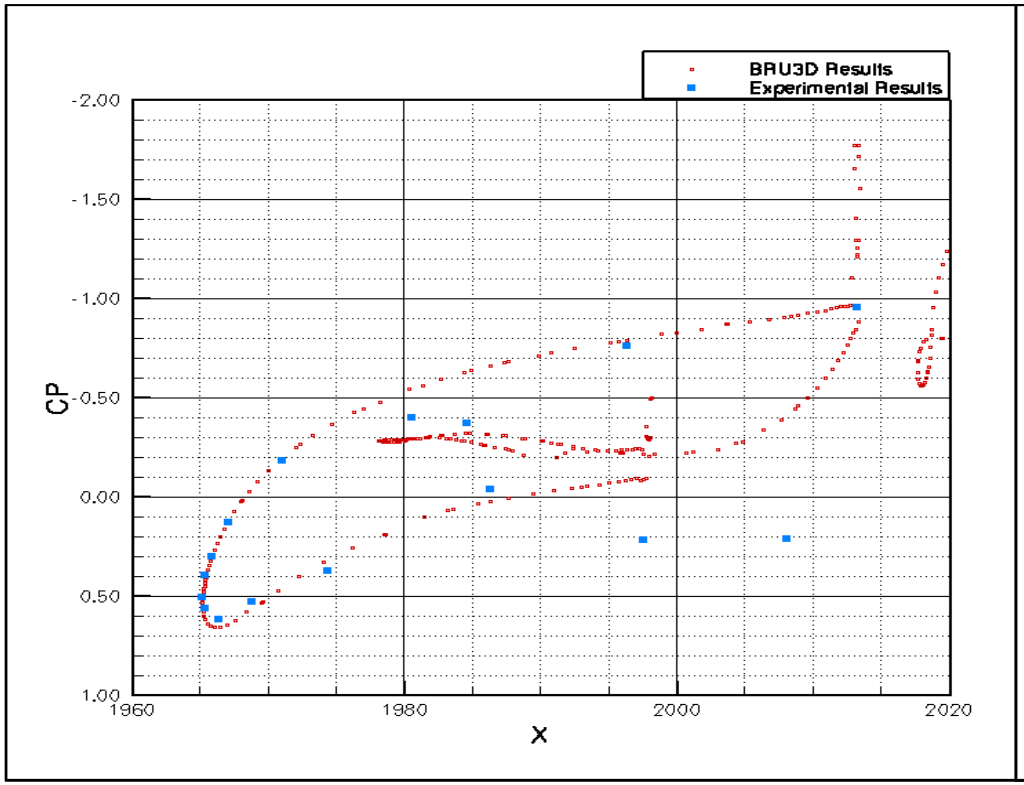
- Postprocessing: Surface Data Extraction for JSM (Case 2)



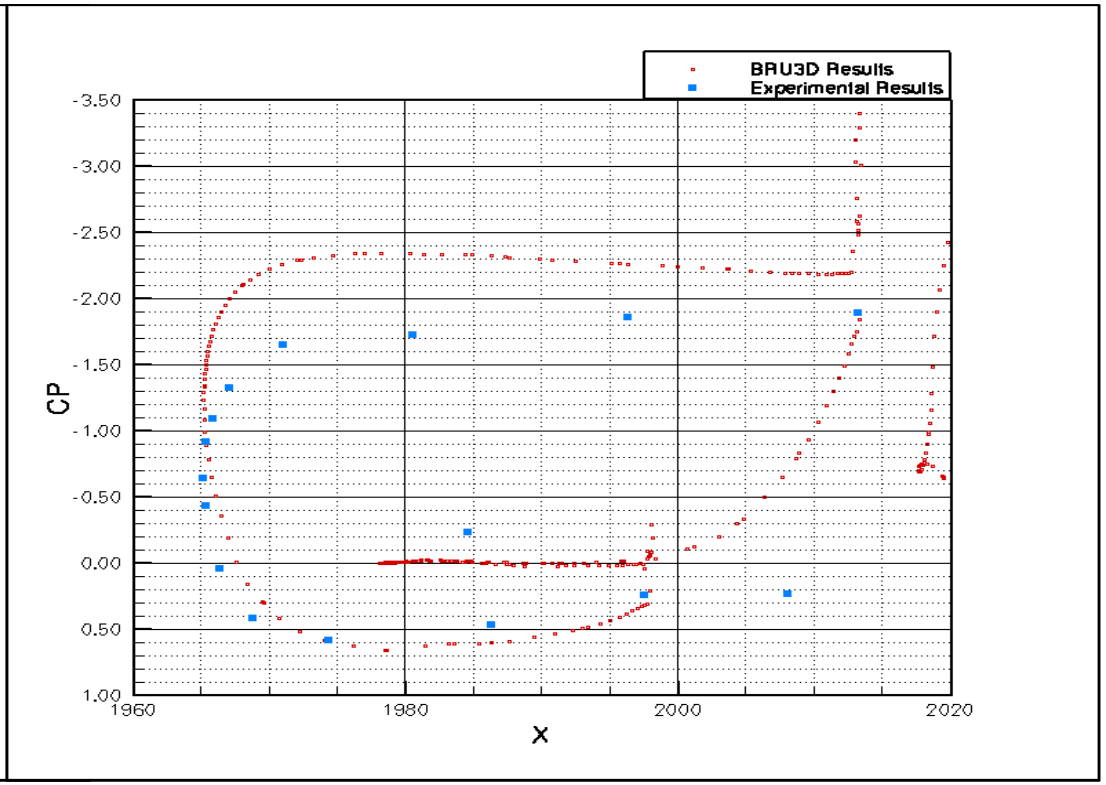
CASE 2a - WB
Comparison of CP distribution

- WB – SLAT B – B

AOA = 4.36 deg



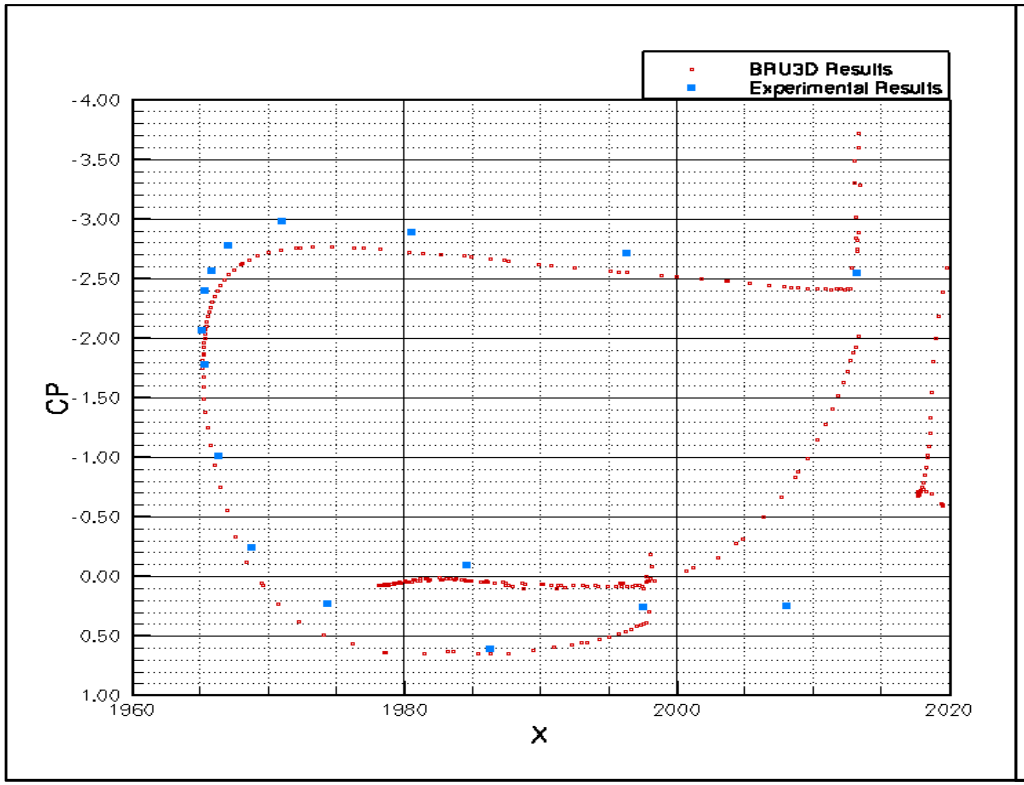
AOA = 10.47 deg



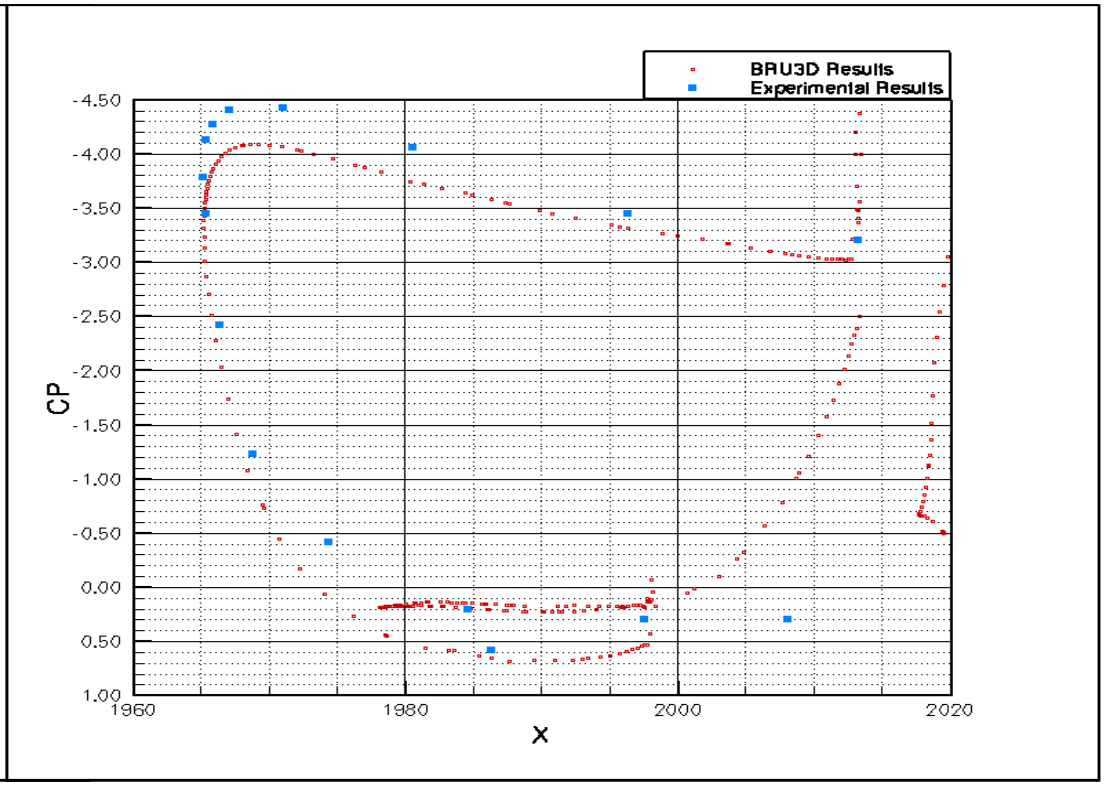
CASE 2a - WB
Comparison of CP distribution

- WB – SLAT B – B

AOA = 14.54 deg



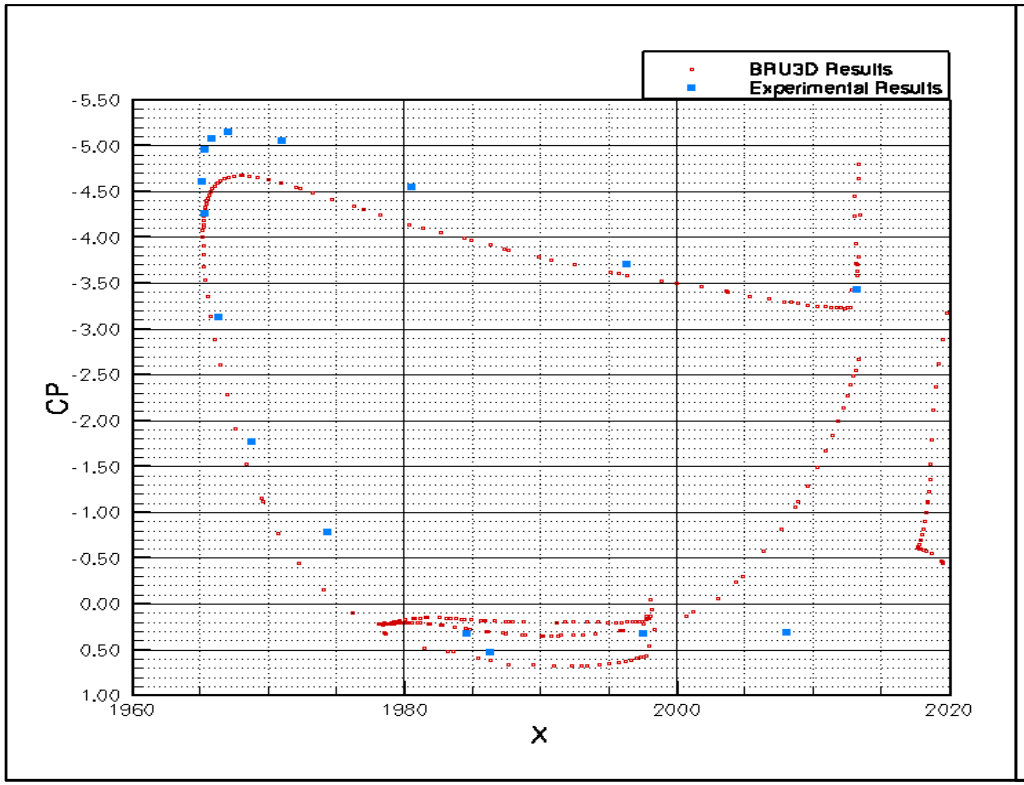
AOA = 18.58 deg



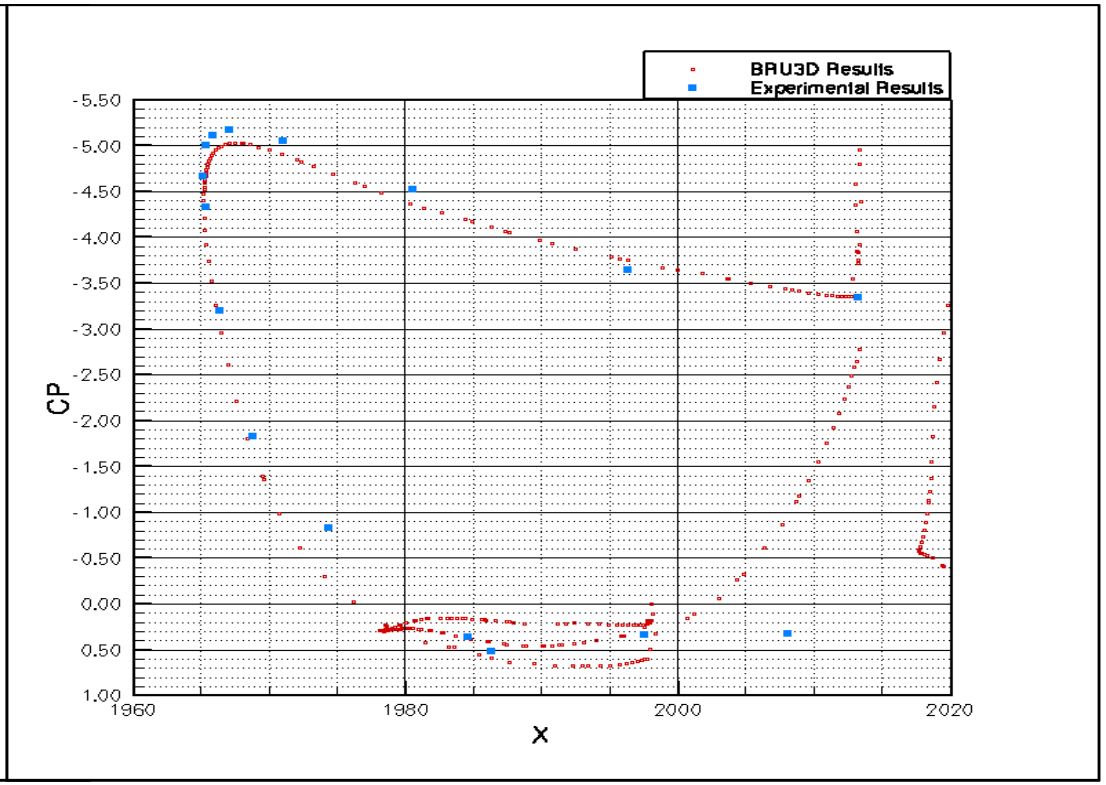
CASE 2a - WB
Comparison of CP distribution

- WB – SLAT B – B

AOA = 20.57 deg



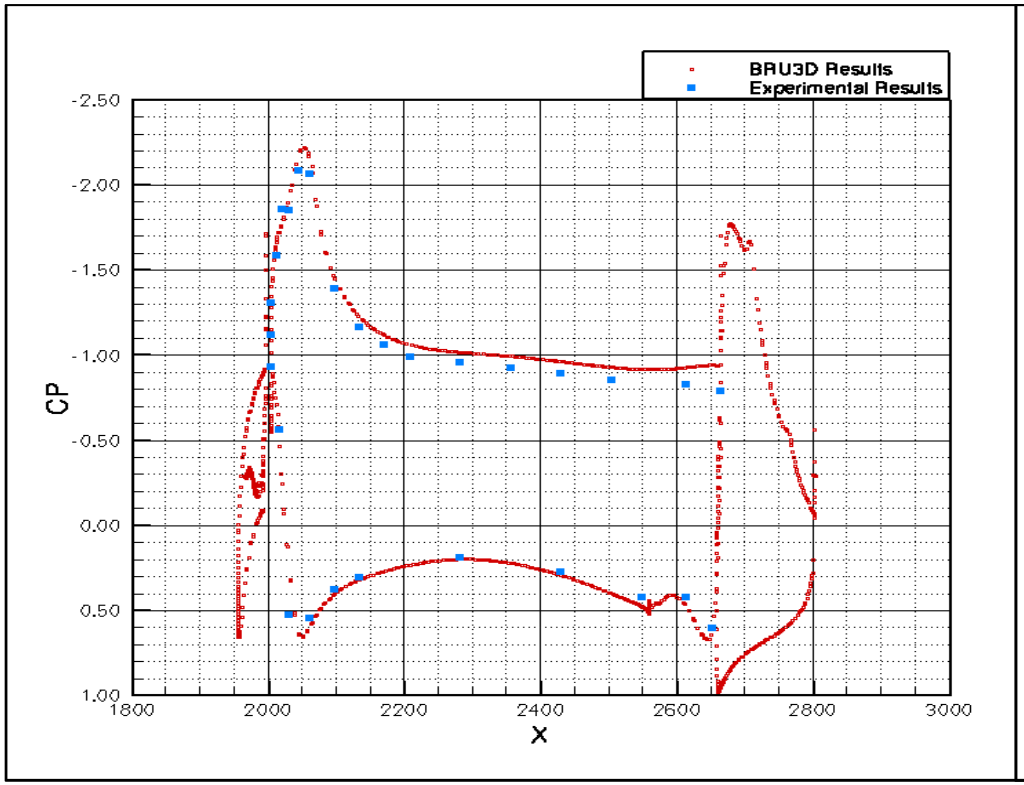
AOA = 21.59 deg



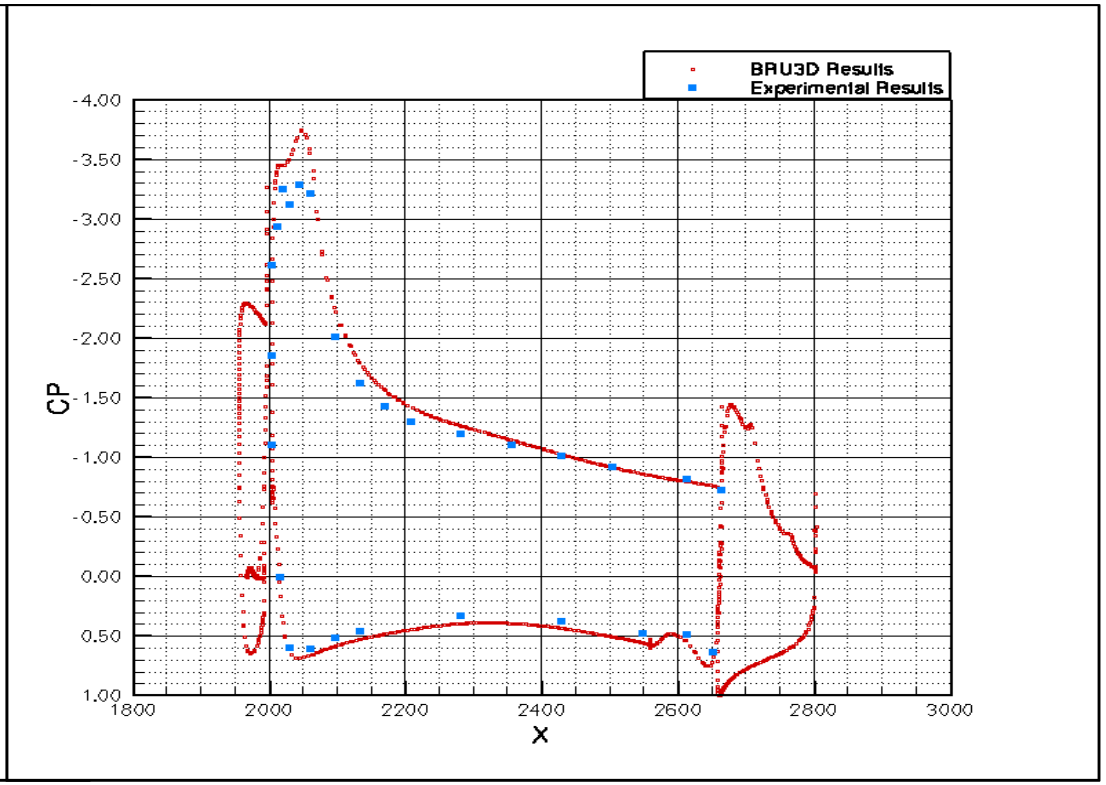
CASE 2a - WB
Comparison of CP distribution

- WB – MAIN ELEMENT B – B

AOA = 4.36 deg



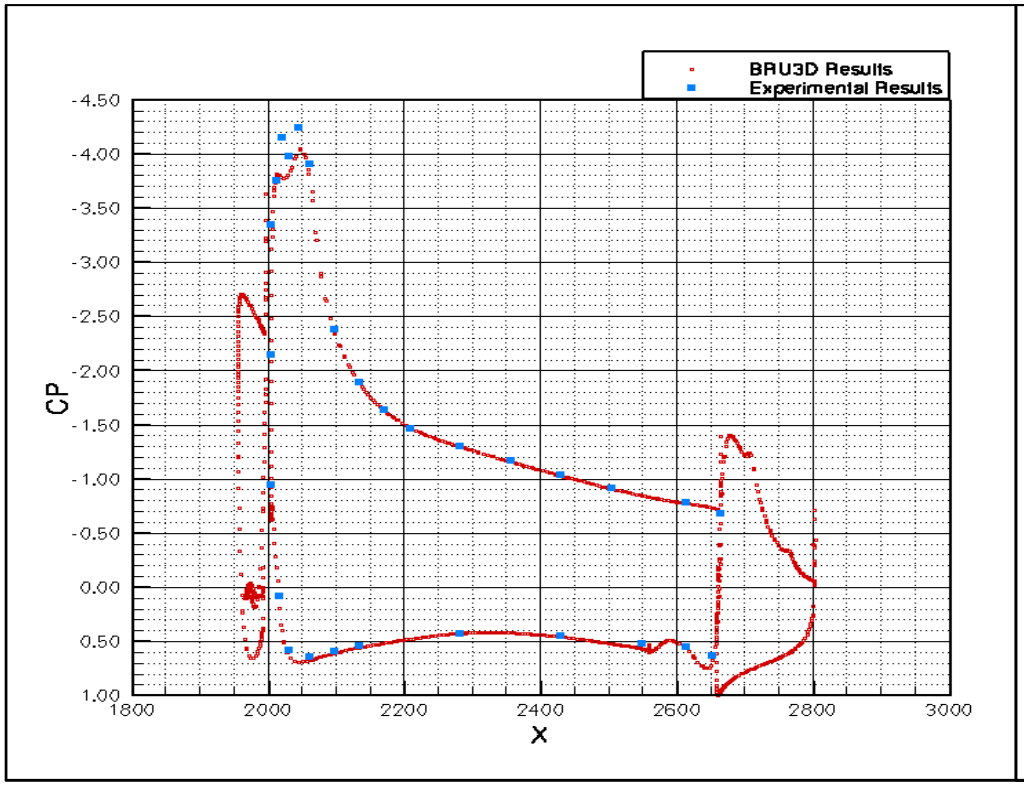
AOA = 10.47 deg



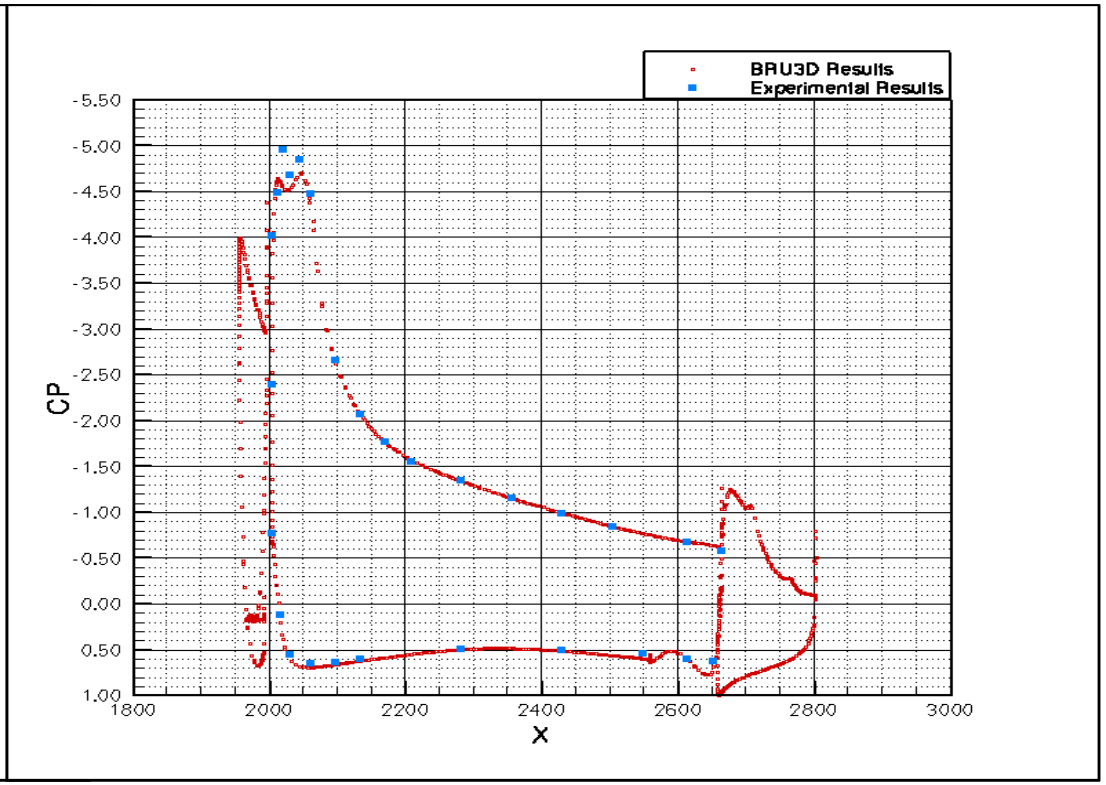
CASE 2a - WB
Comparison of CP distribution

- WB – MAIN ELEMENT B – B

AOA = 14.54 deg



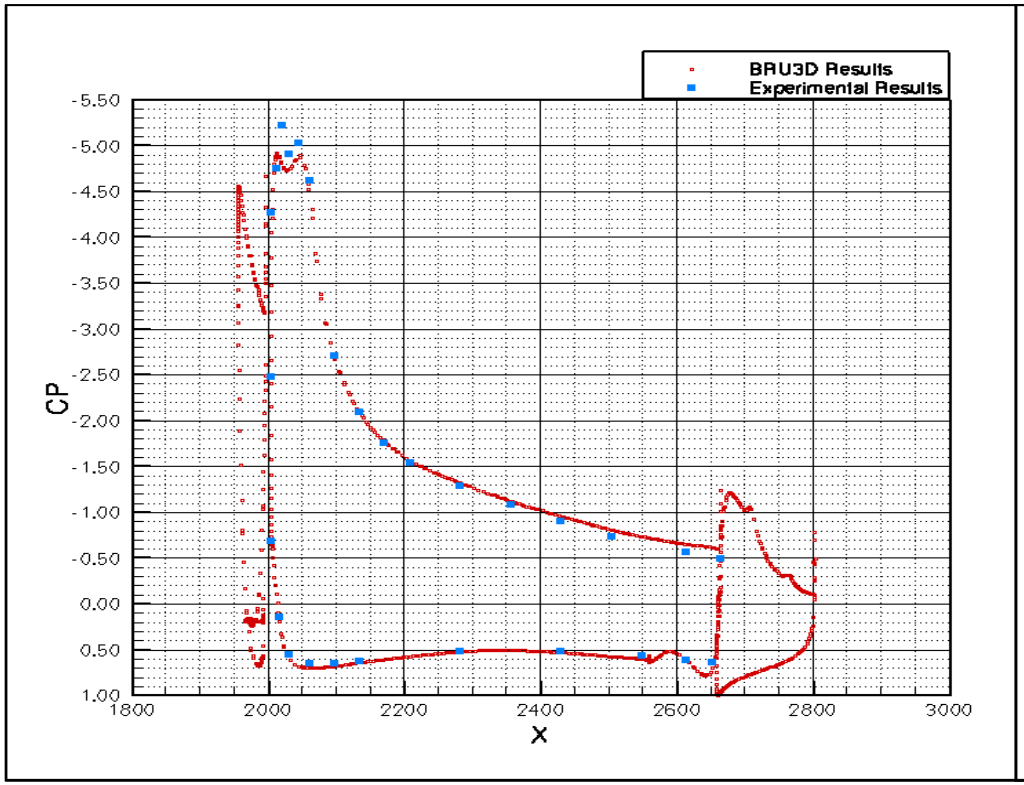
AOA = 18.58 deg



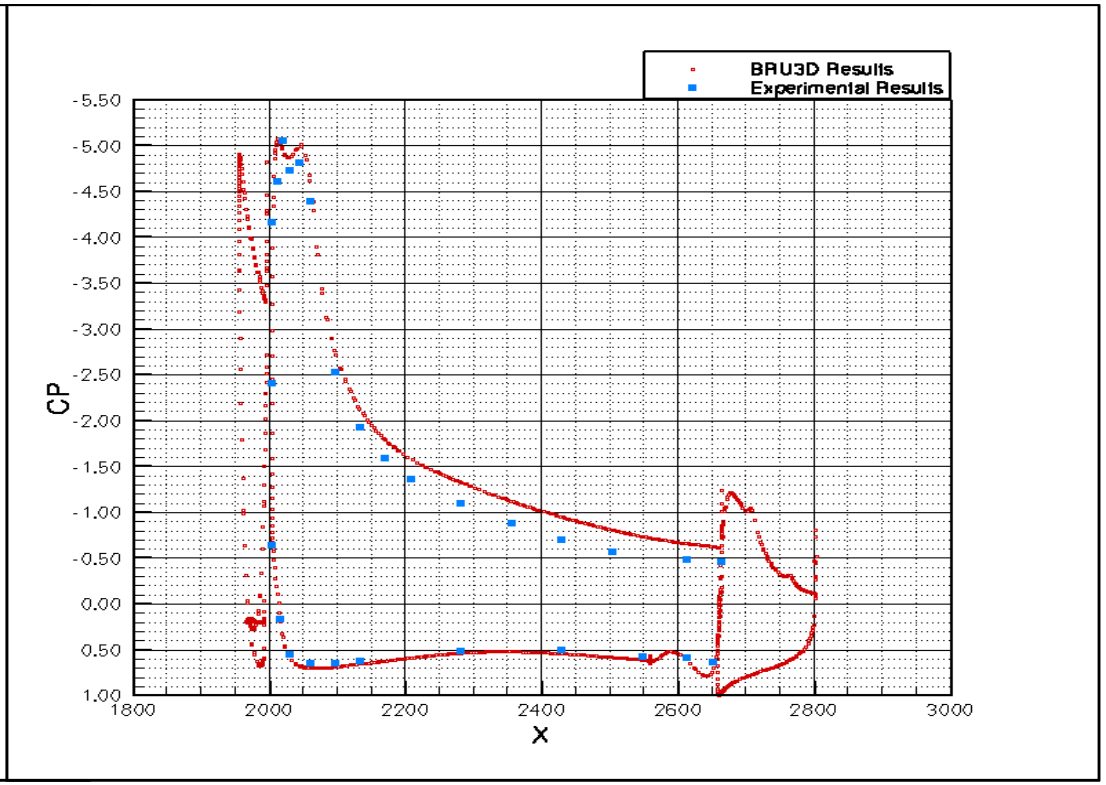
CASE 2a - WB
Comparison of CP distribution

- WB – MAIN ELEMENT B – B

AOA = 20.57 deg



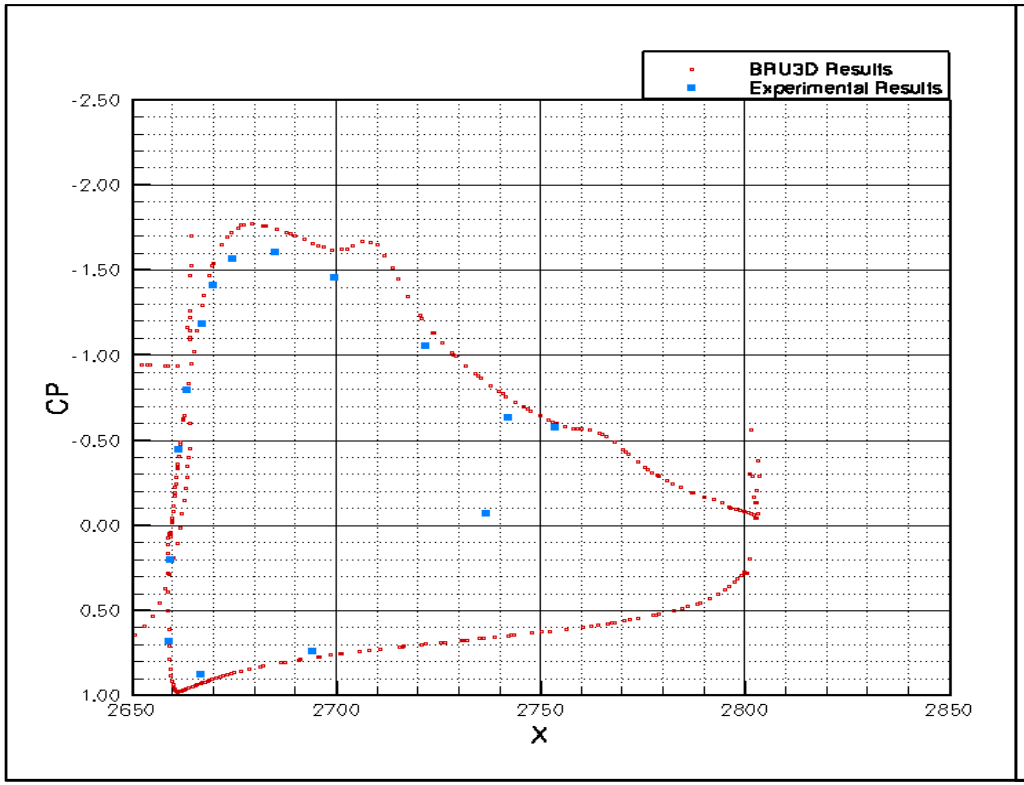
AOA = 21.59 deg



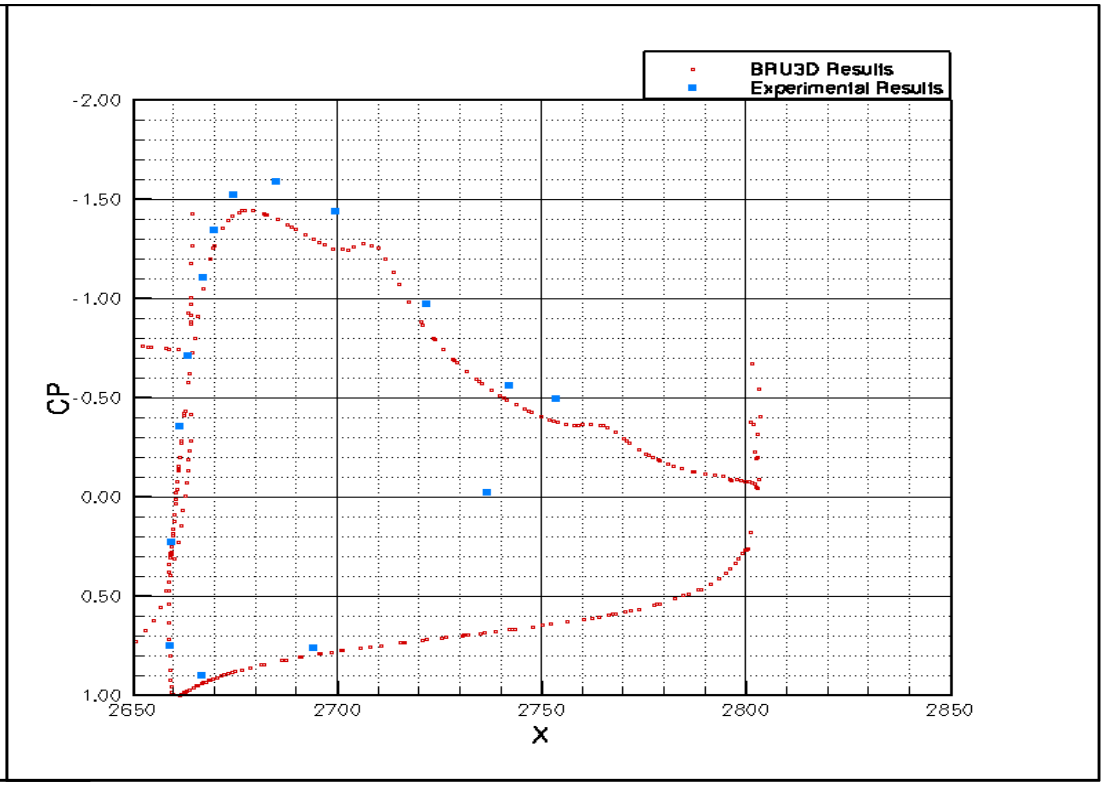
CASE 2a - WB
Comparison of CP distribution

- WB – FLAP B – B

AOA = 4.36 deg



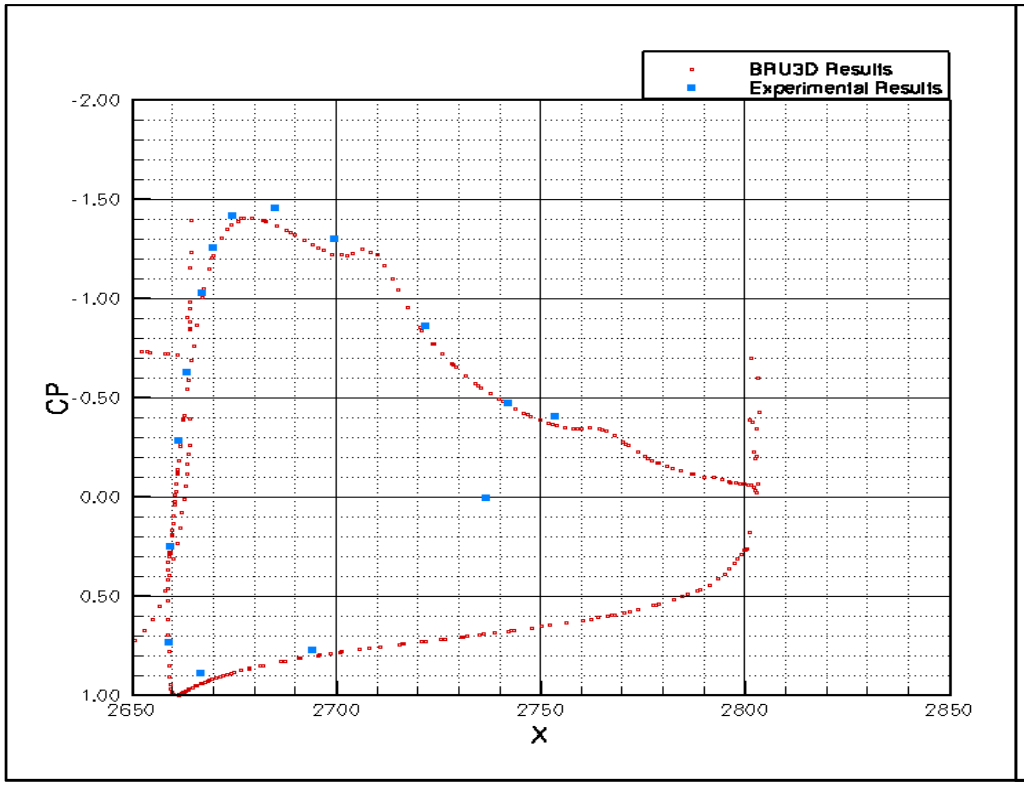
AOA = 10.47 deg



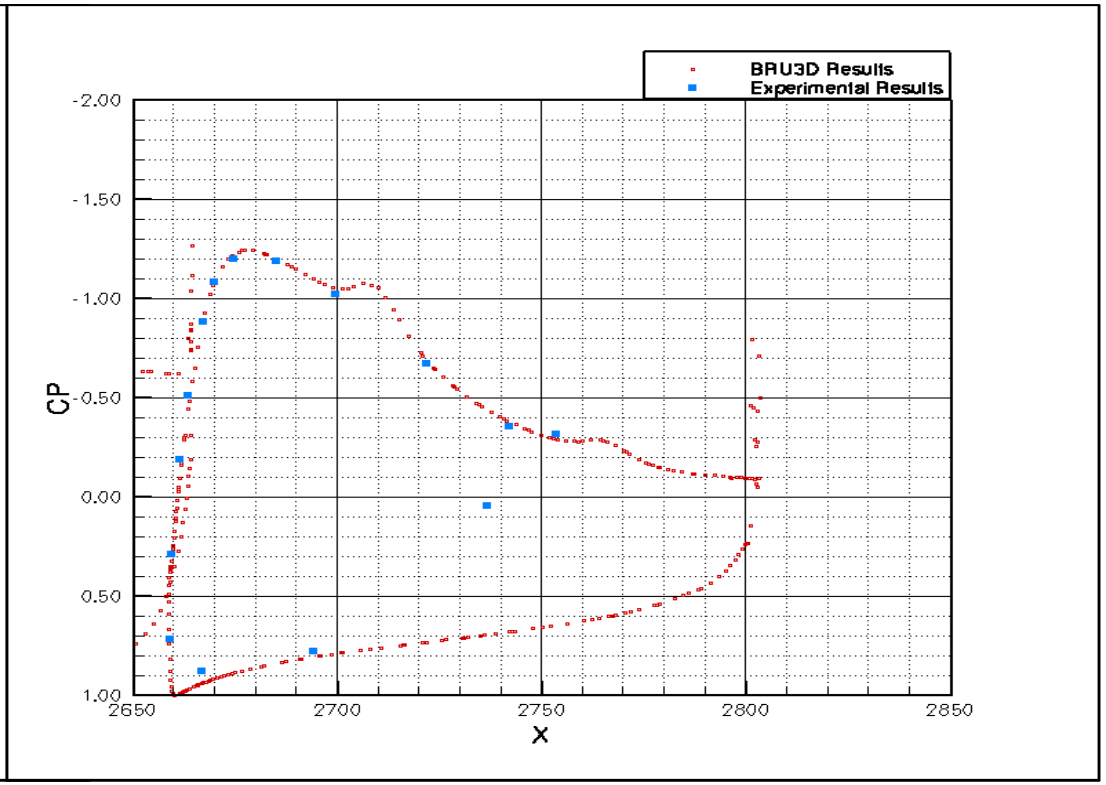
CASE 2a - WB
Comparison of CP distribution

- WB – FLAP B – B

AOA = 14.54 deg



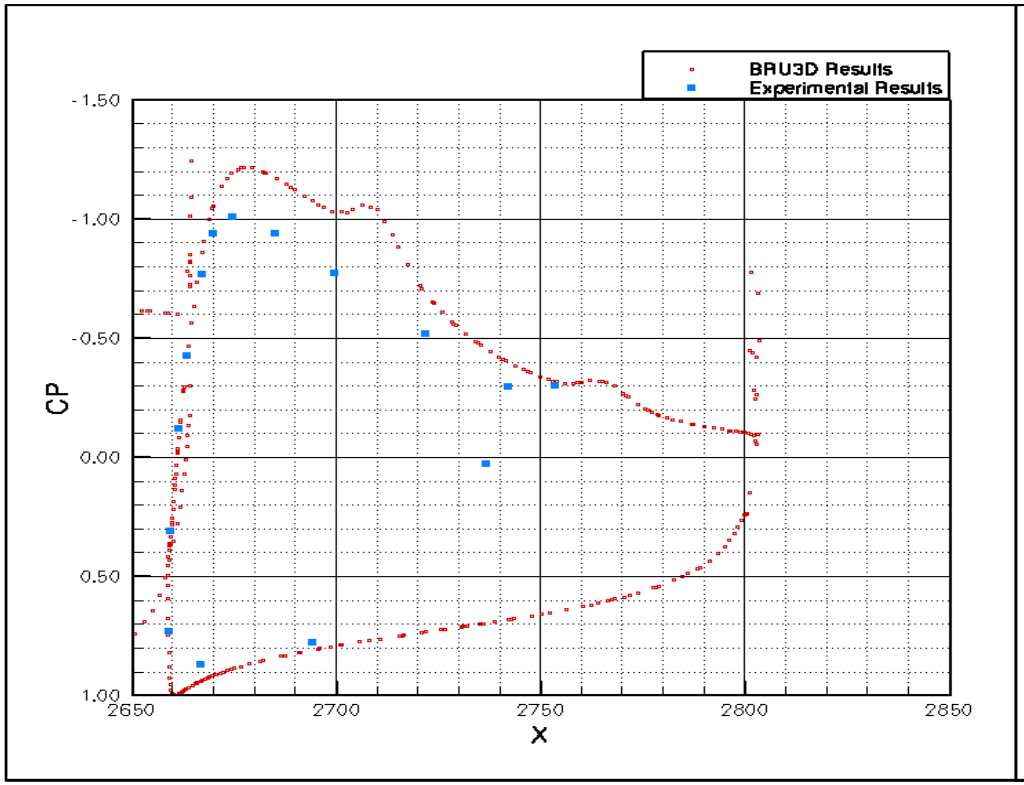
AOA = 18.58 deg



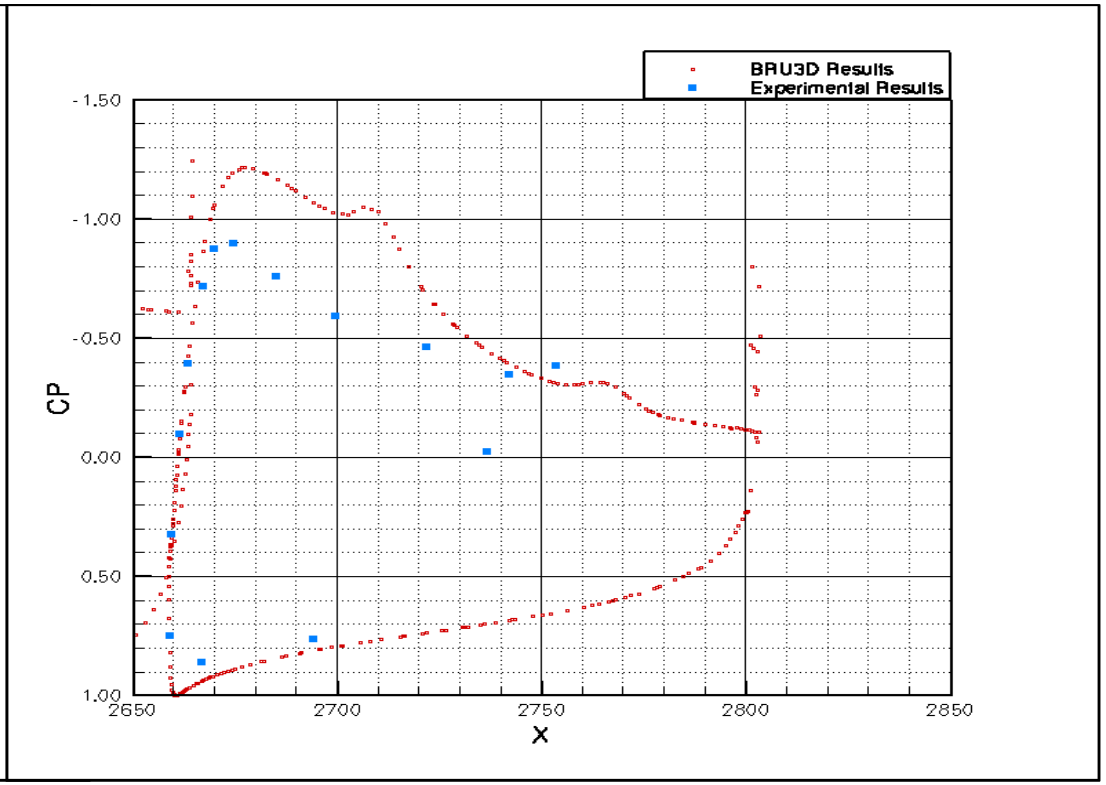
CASE 2a - WB
Comparison of CP distribution

- WB – FLAP B – B

AOA = 20.57 deg

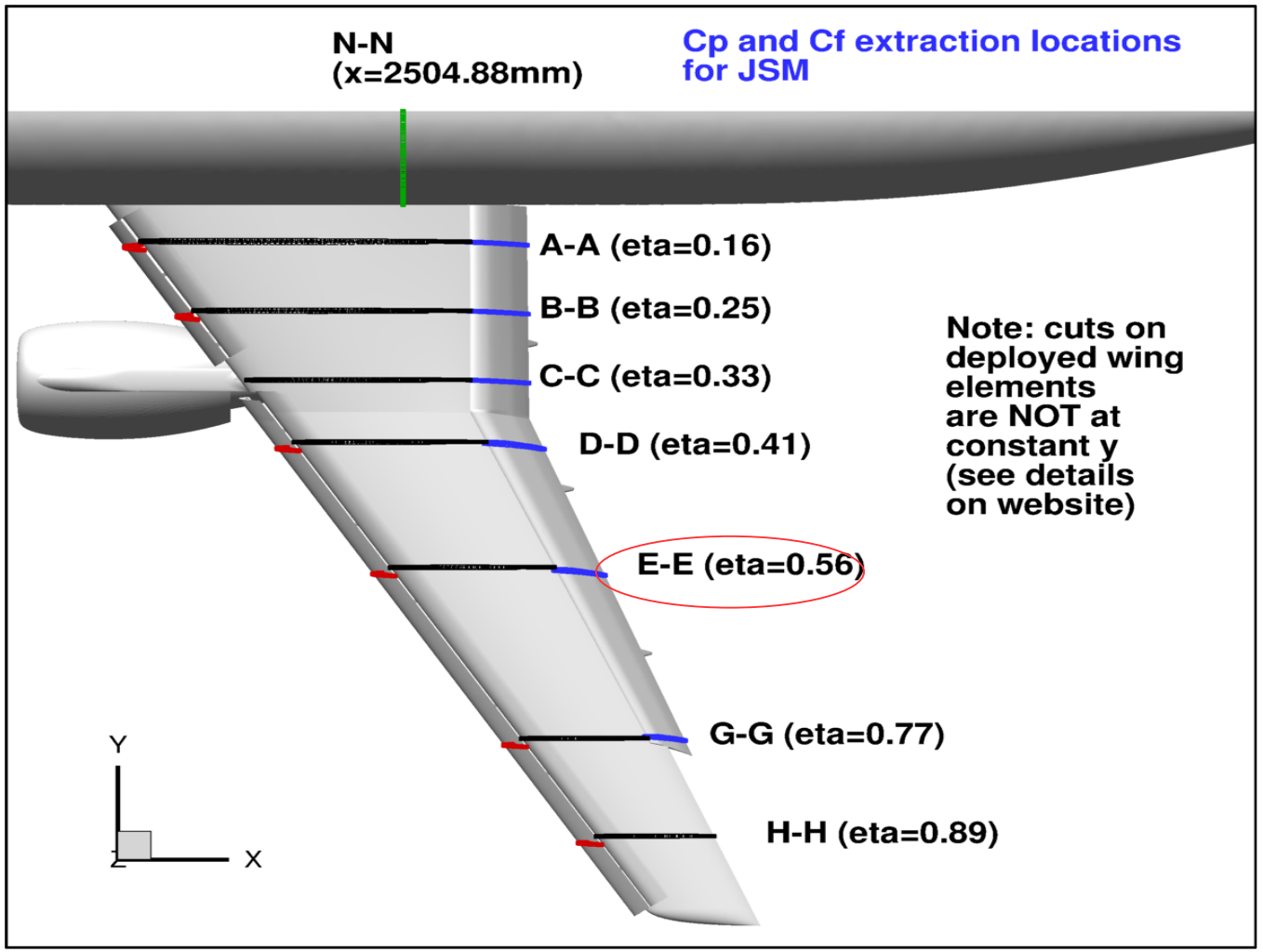


AOA = 21.59 deg



CASE 2a - WB
Comparison of CP distribution

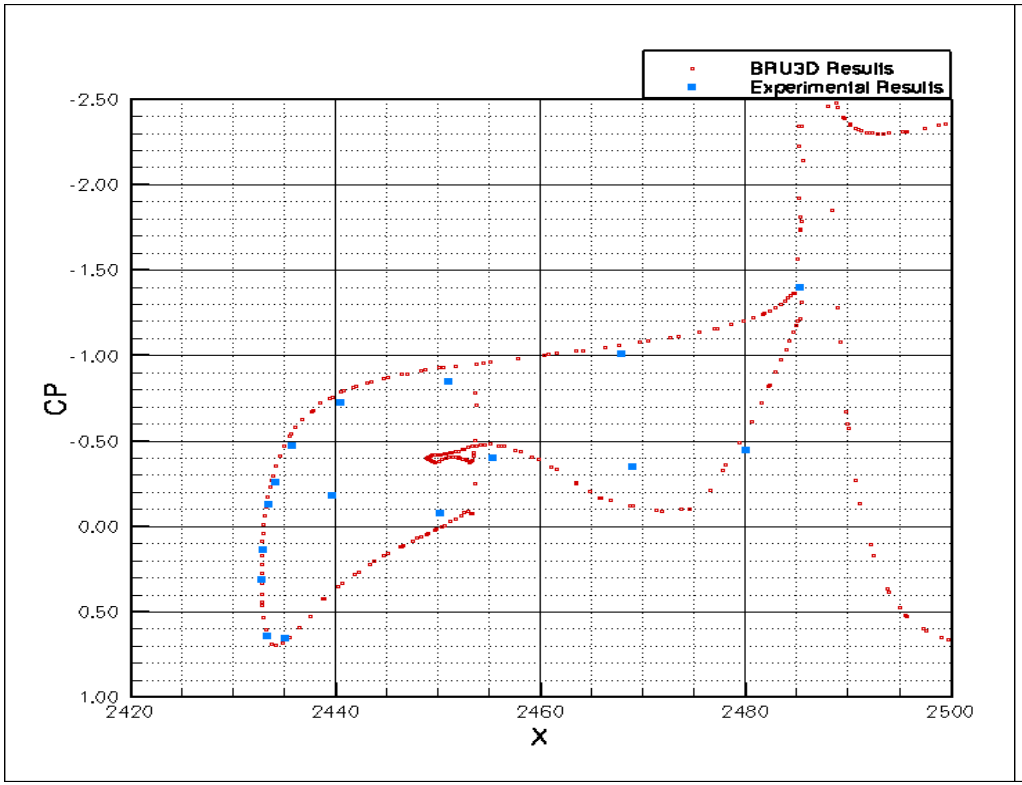
- Postprocessing: Surface Data Extraction for JSM (Case 2)



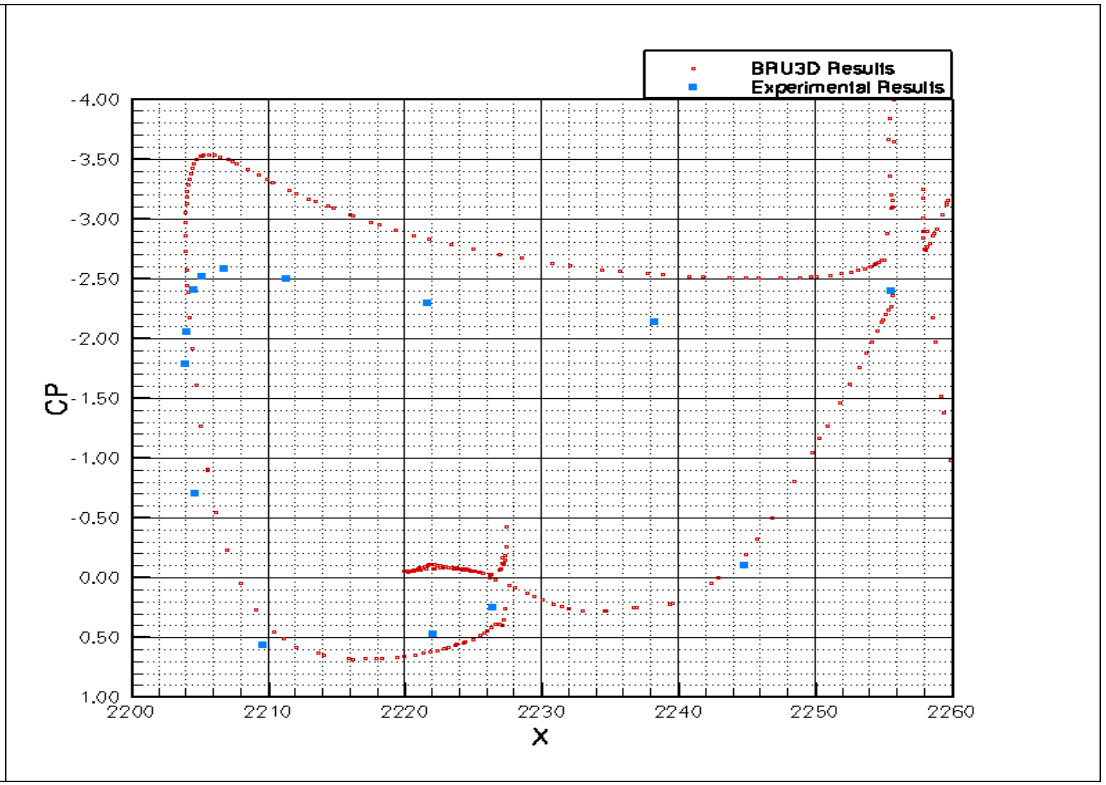
CASE 2a - WB
Comparison of CP distribution

- WB – SLAT E - E

AOA = 4.36 deg



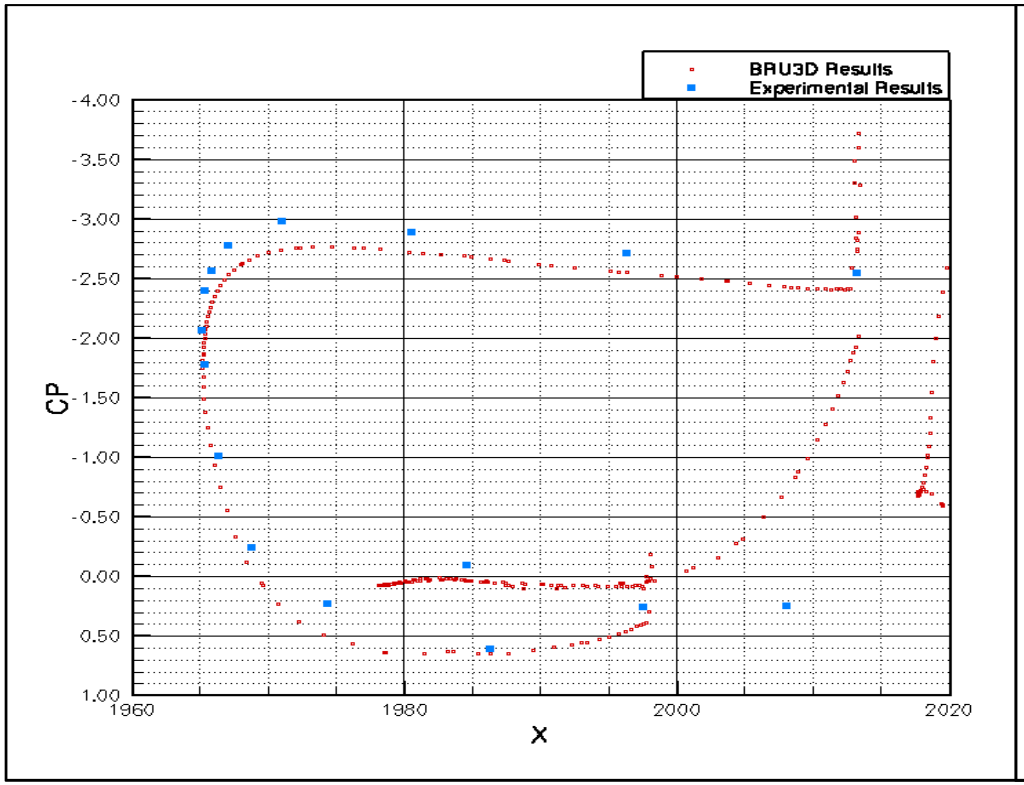
AOA = 10.47 deg



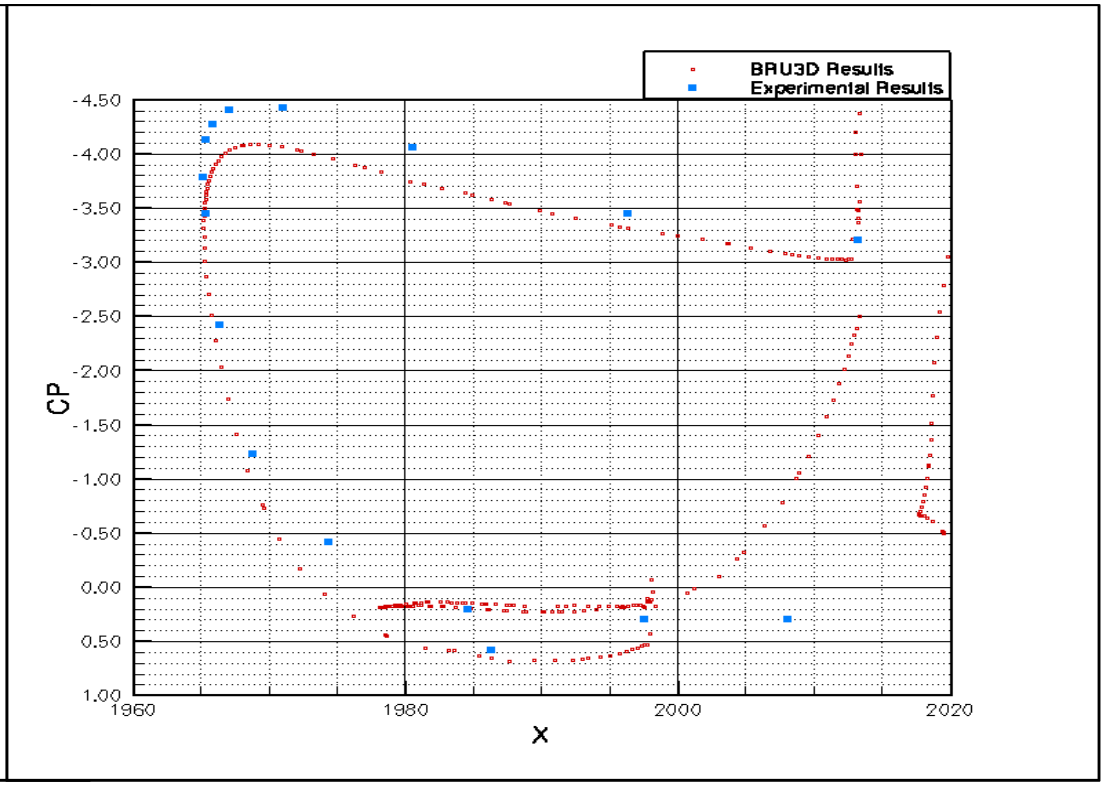
CASE 2a - WB
Comparison of CP distribution

- WB – SLAT E - E

AOA = 14.54 deg



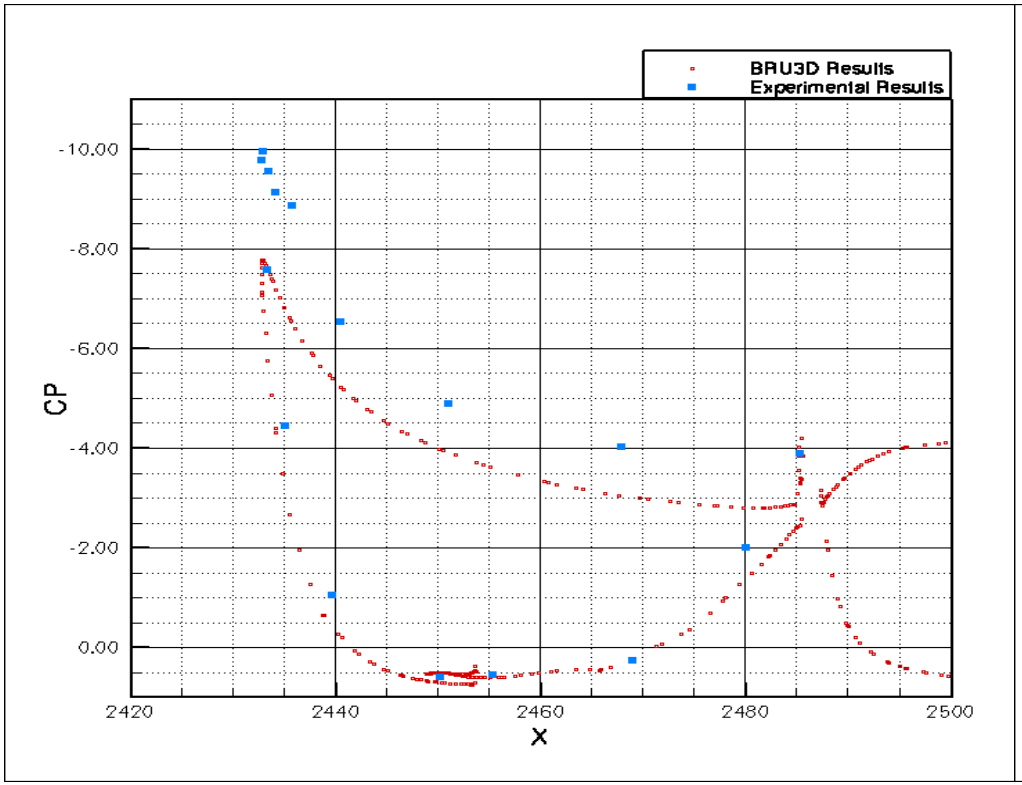
AOA = 18.58 deg



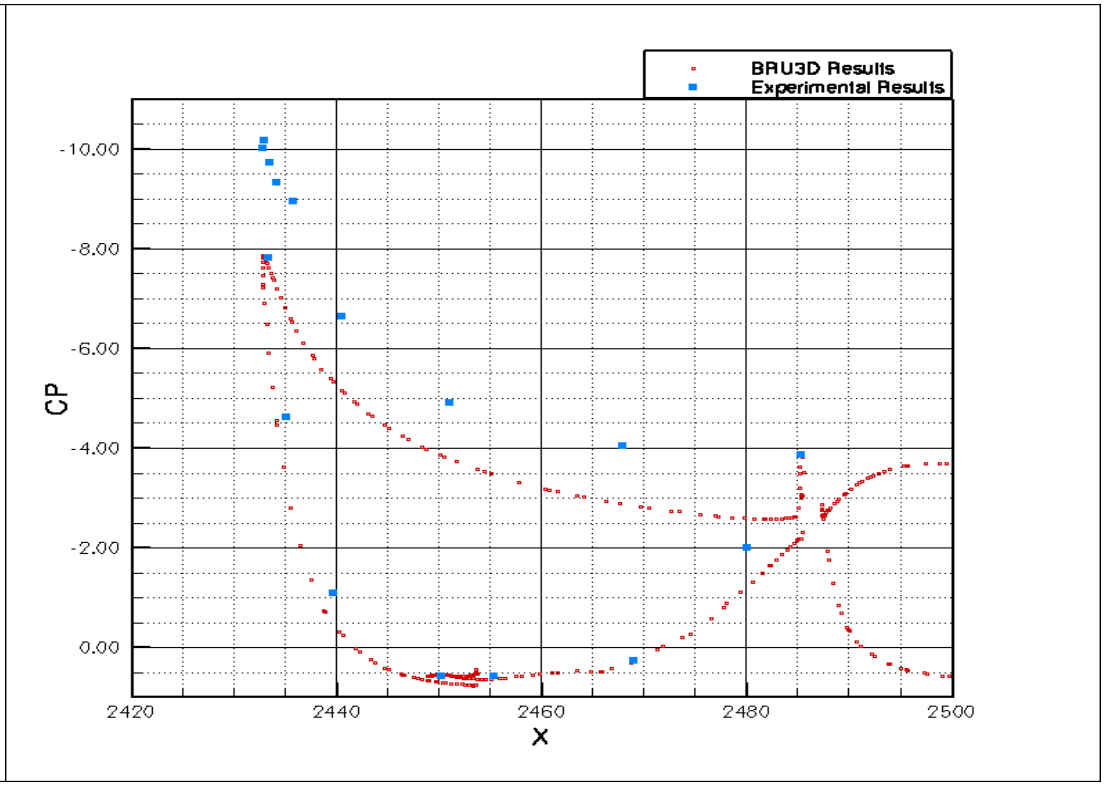
CASE 2a - WB
Comparison of CP distribution

- WB – SLAT E - E

AOA = 20.57 deg



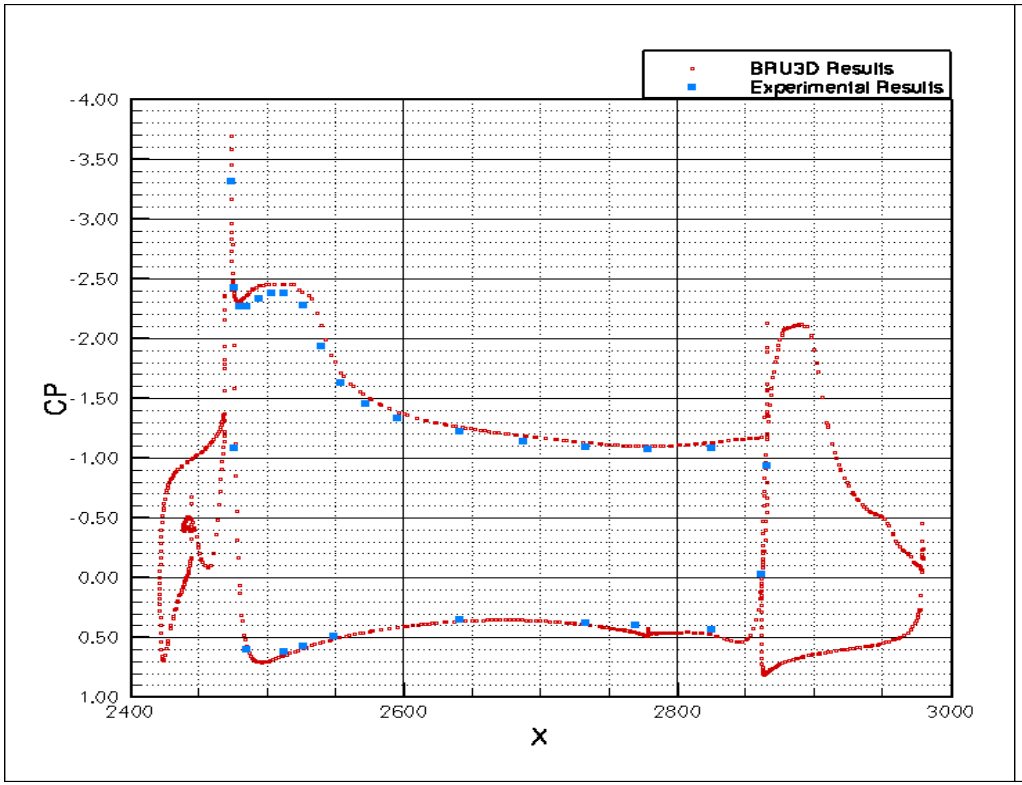
AOA = 21.59 deg



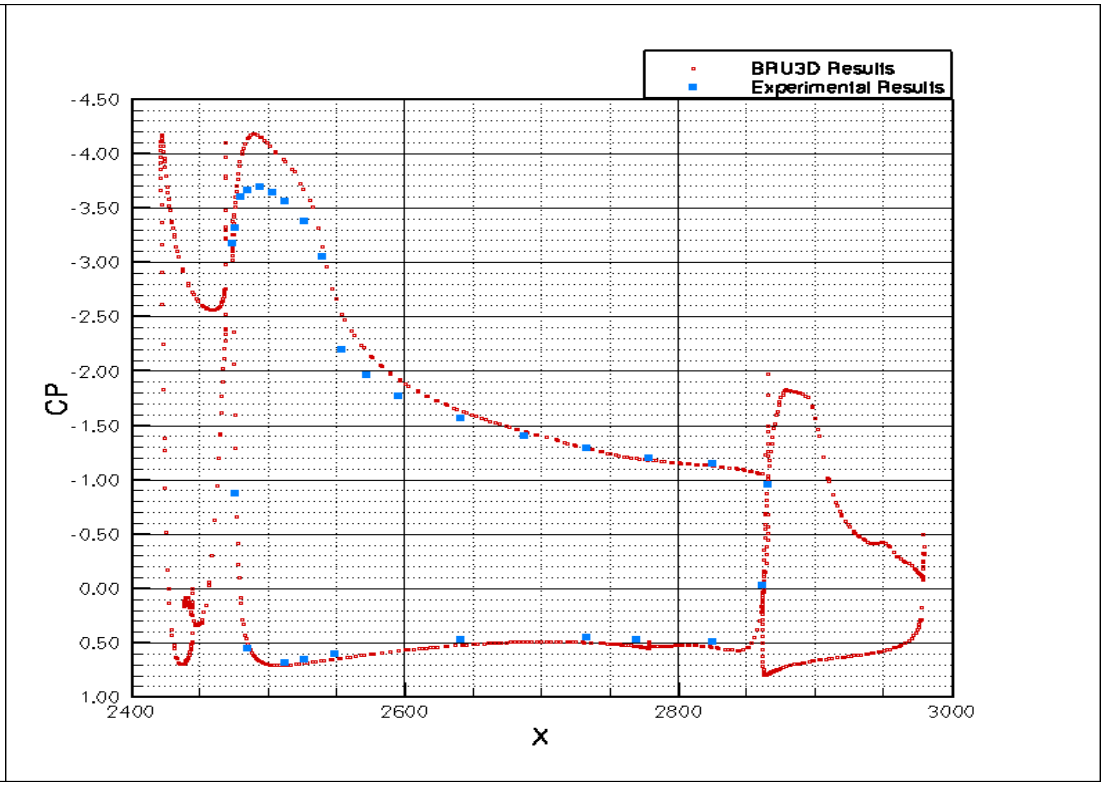
CASE 2a - WB
Comparison of CP distribution

- WB – MAIN ELEMENT E - E

AOA = 4.36 deg



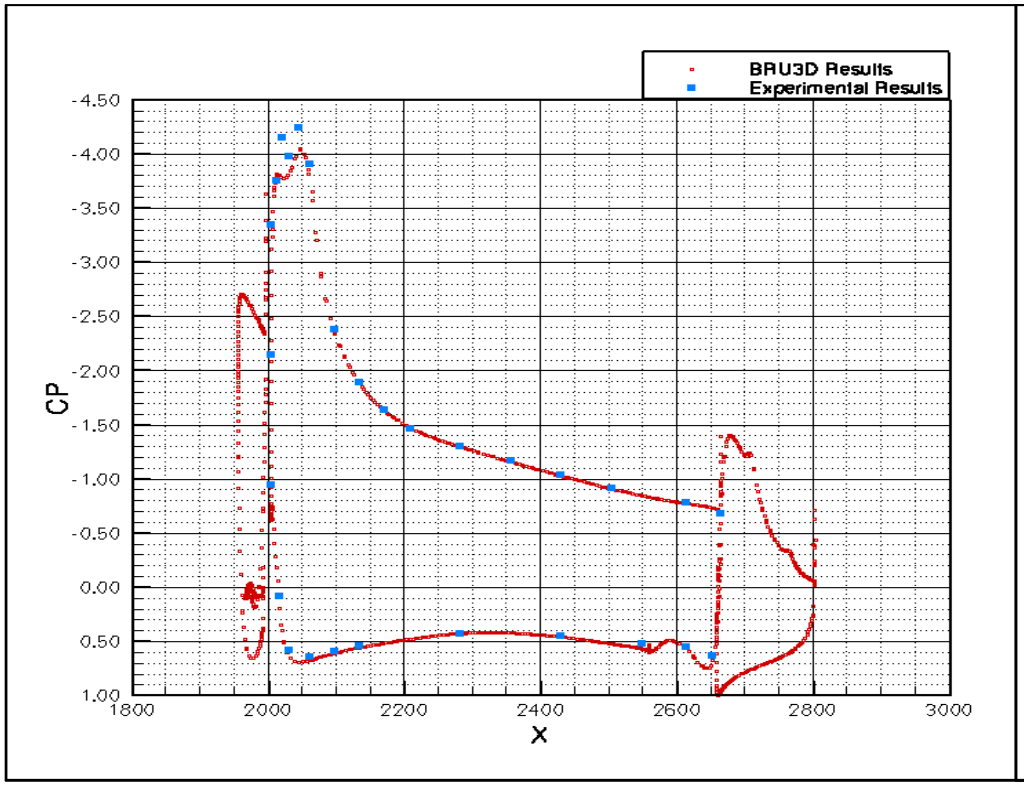
AOA = 10.47 deg



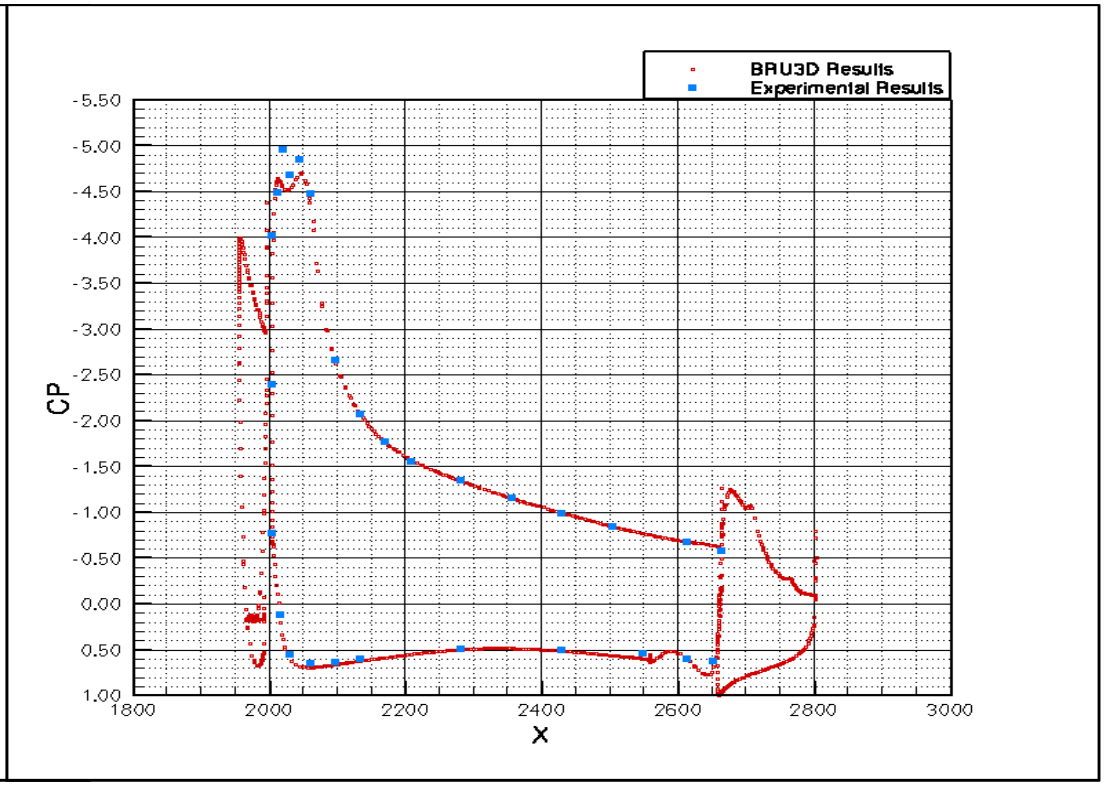
CASE 2a - WB
Comparison of CP distribution

- WB – MAIN ELEMENT E - E

AOA = 14.54 deg



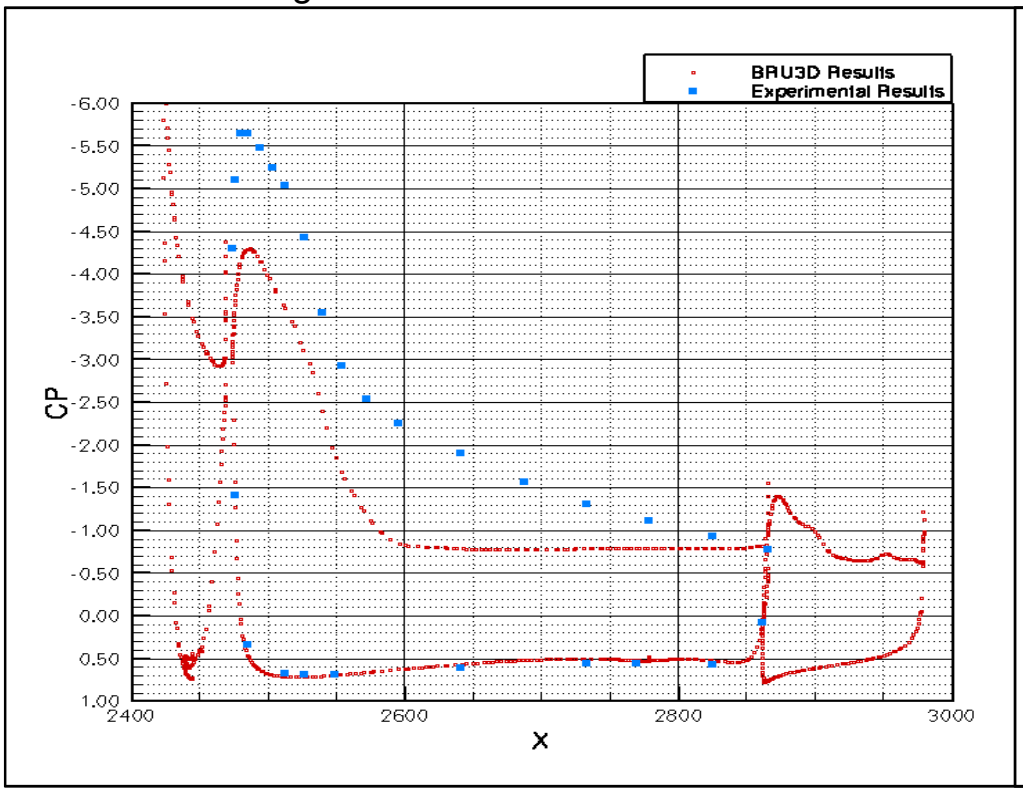
AOA = 18.58 deg



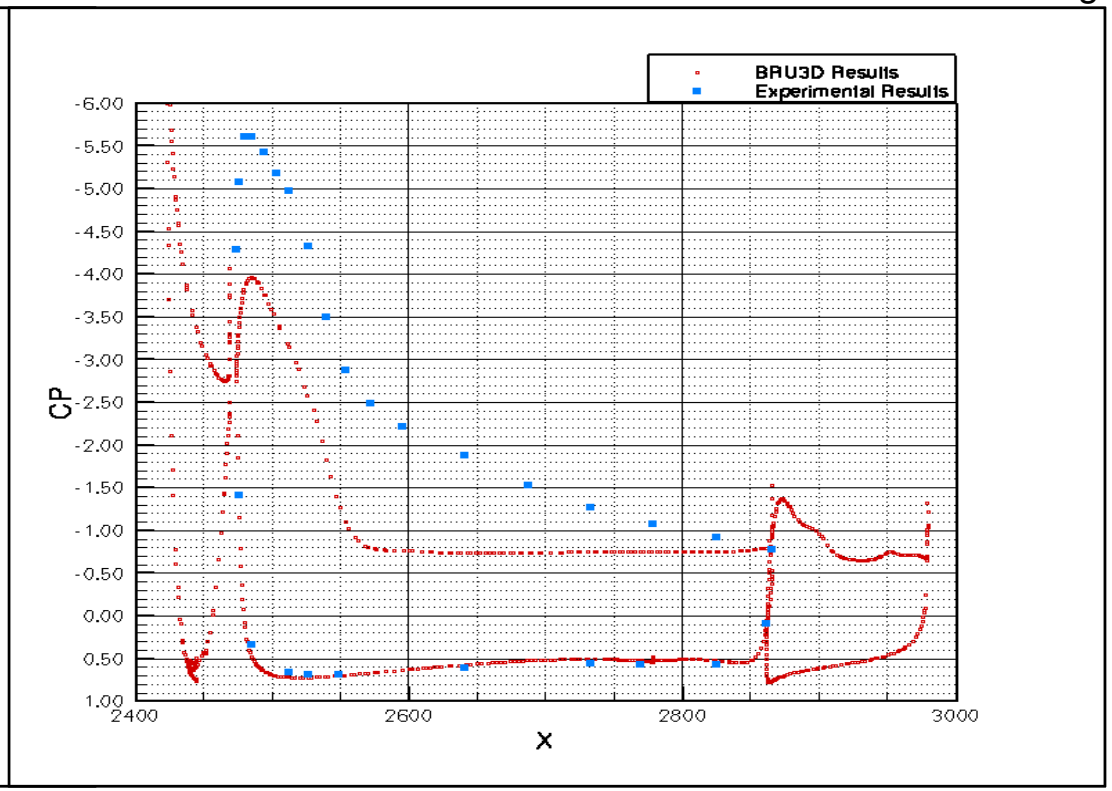
CASE 2a - WB
Comparison of CP distribution

- WB – MAIN ELEMENT E - E

AOA = 20.57 deg



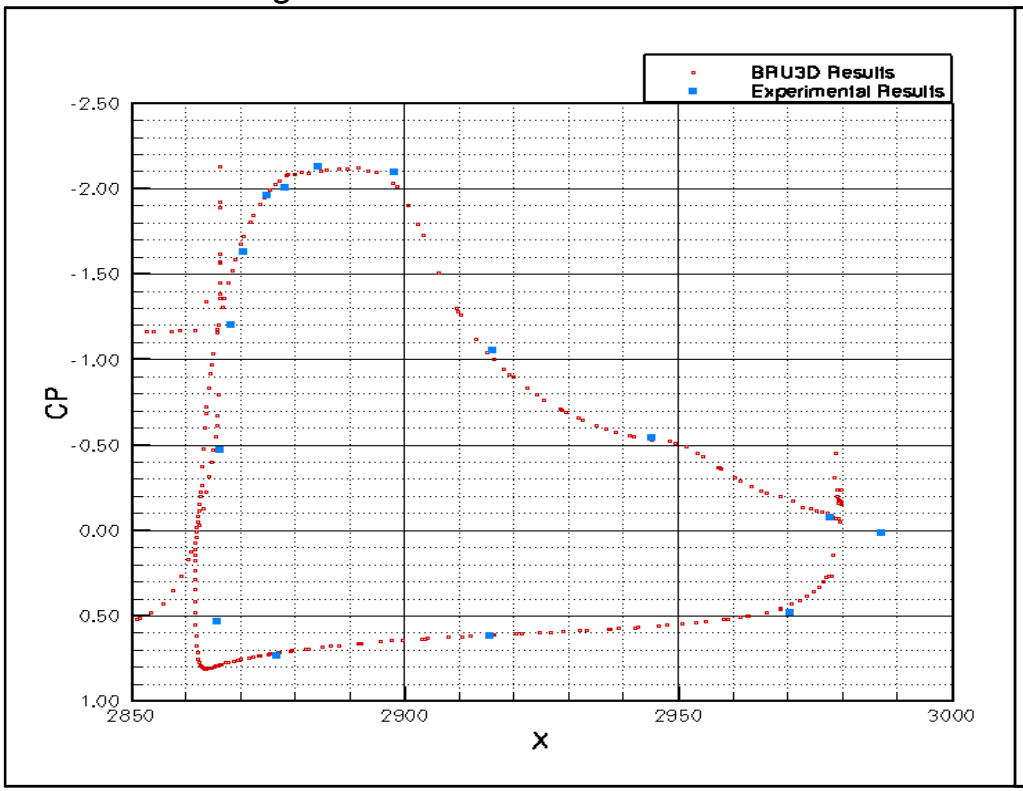
AOA = 21.59 deg



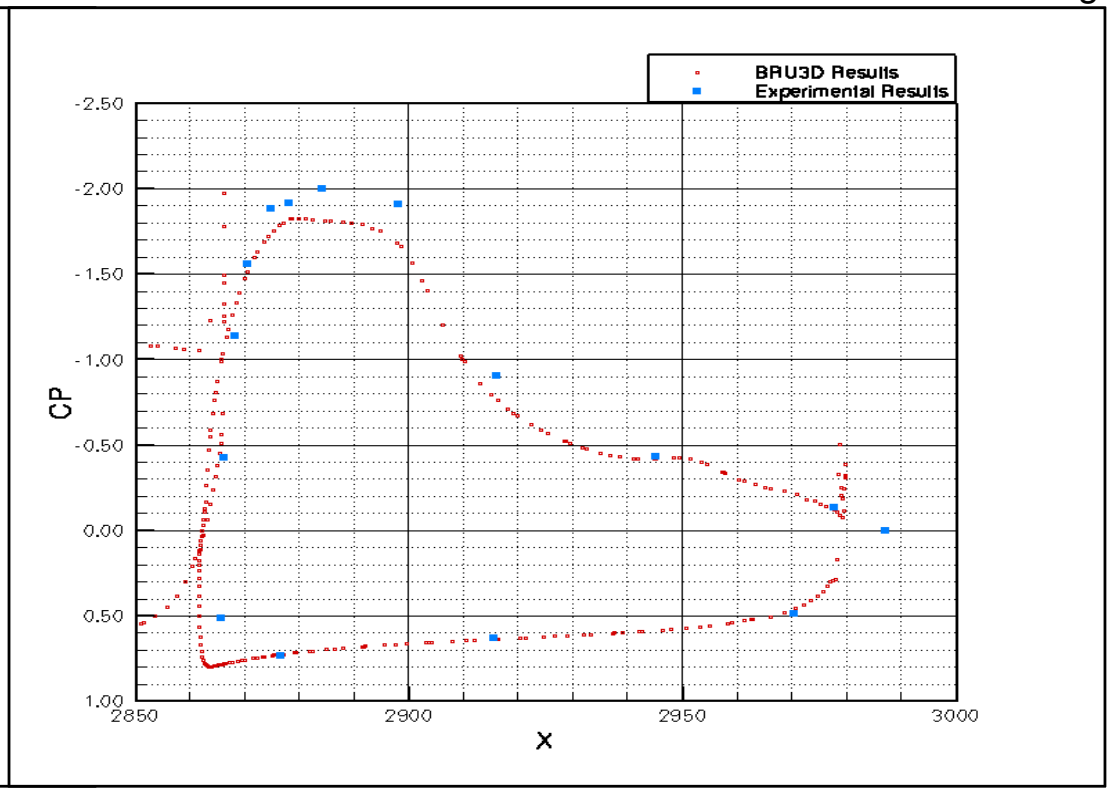
CASE 2a - WB
Comparison of CP distribution

- WB – FLAP E - E

AOA = 4.36 deg



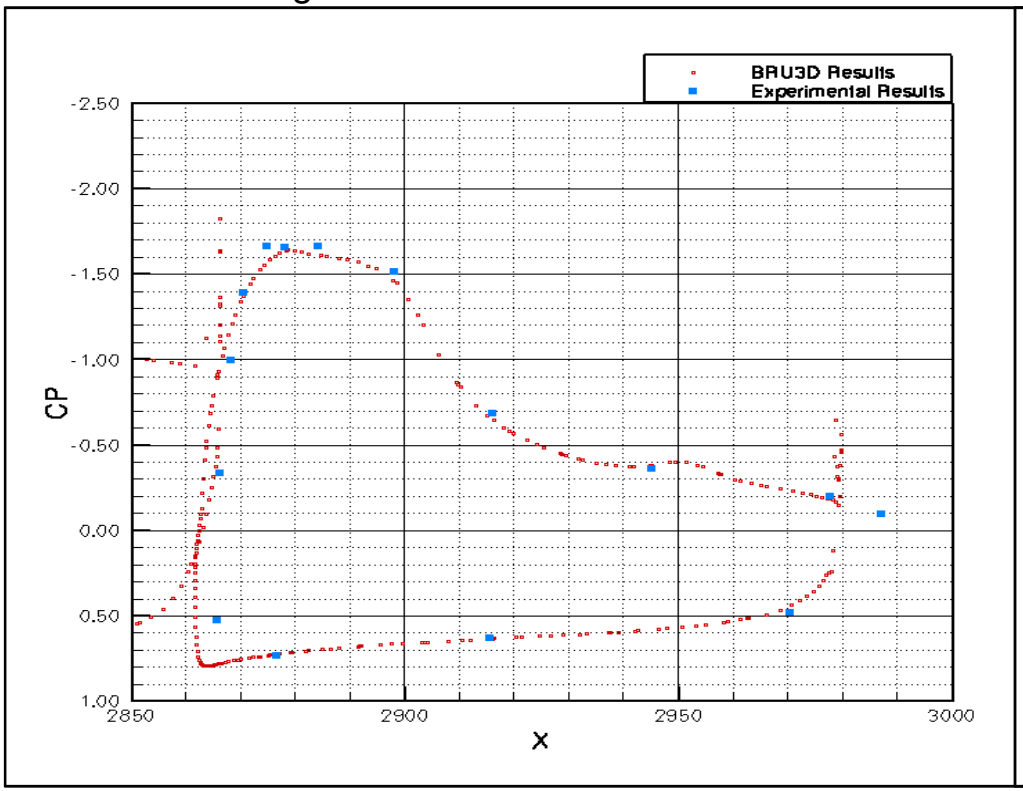
AOA = 10.47 deg



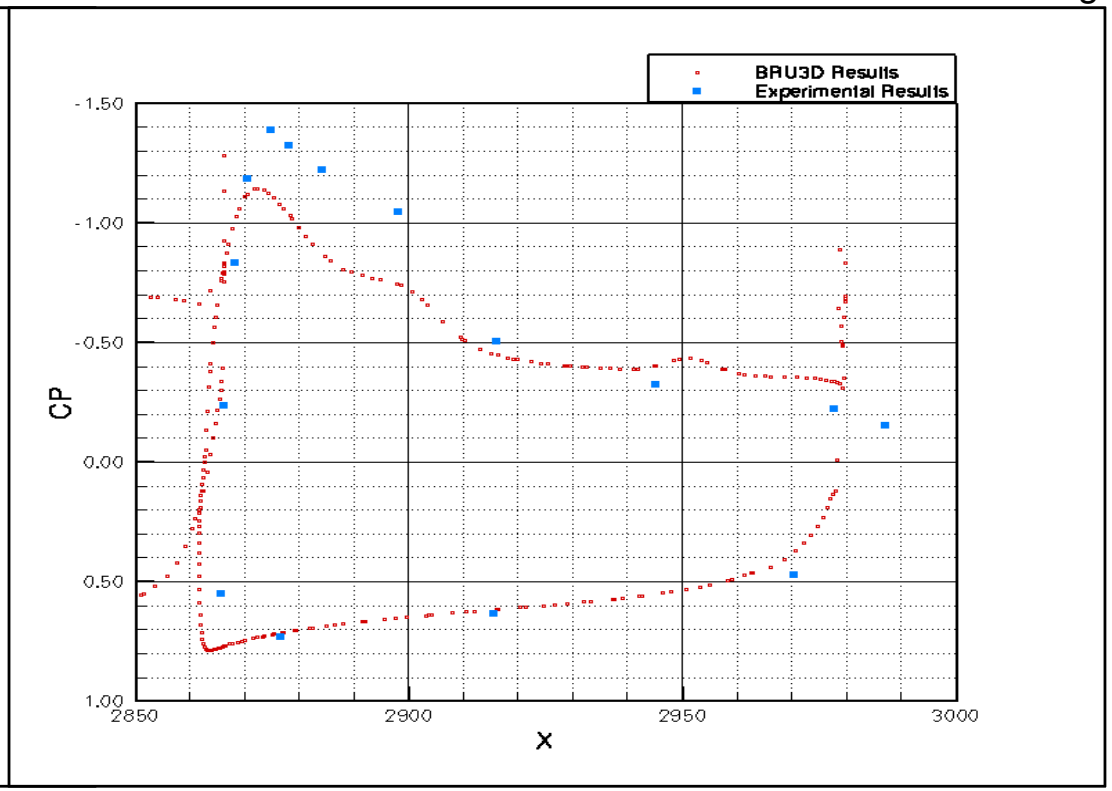
CASE 2a - WB
Comparison of CP distribution

- WB – FLAP E - E

AOA = 14.54 deg



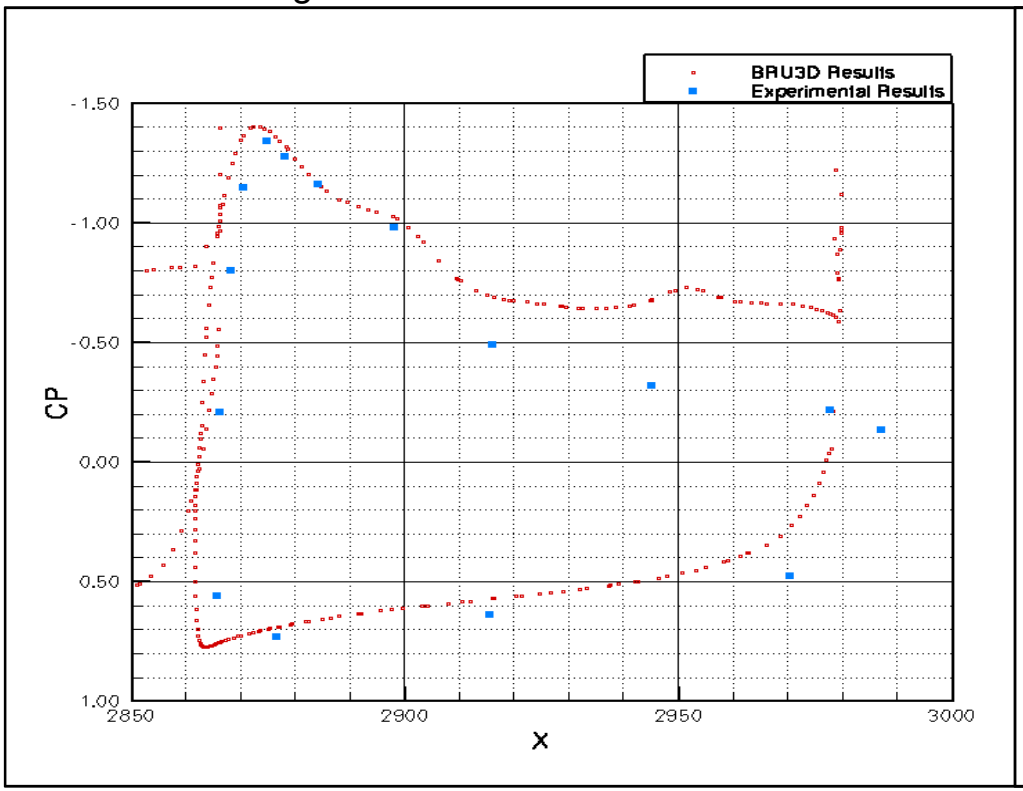
AOA = 18.58 deg



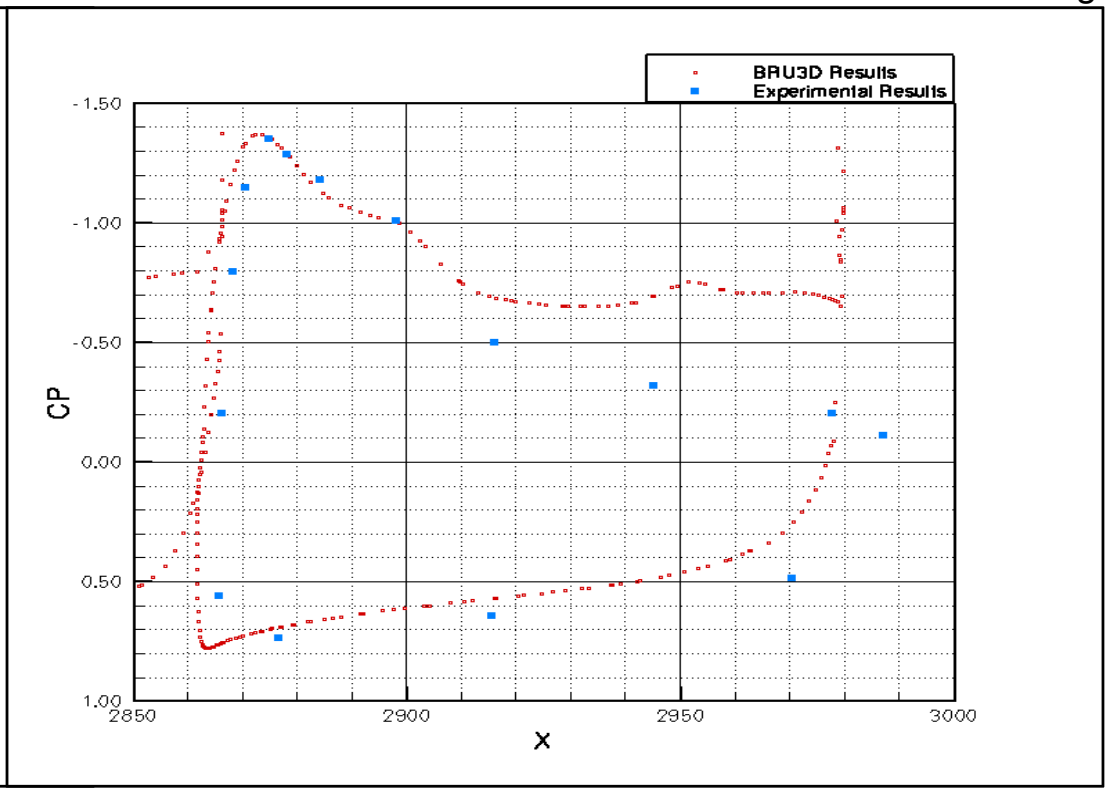
CASE 2a - WB
Comparison of CP distribution

- WB – FLAP E - E

AOA = 20.57 deg

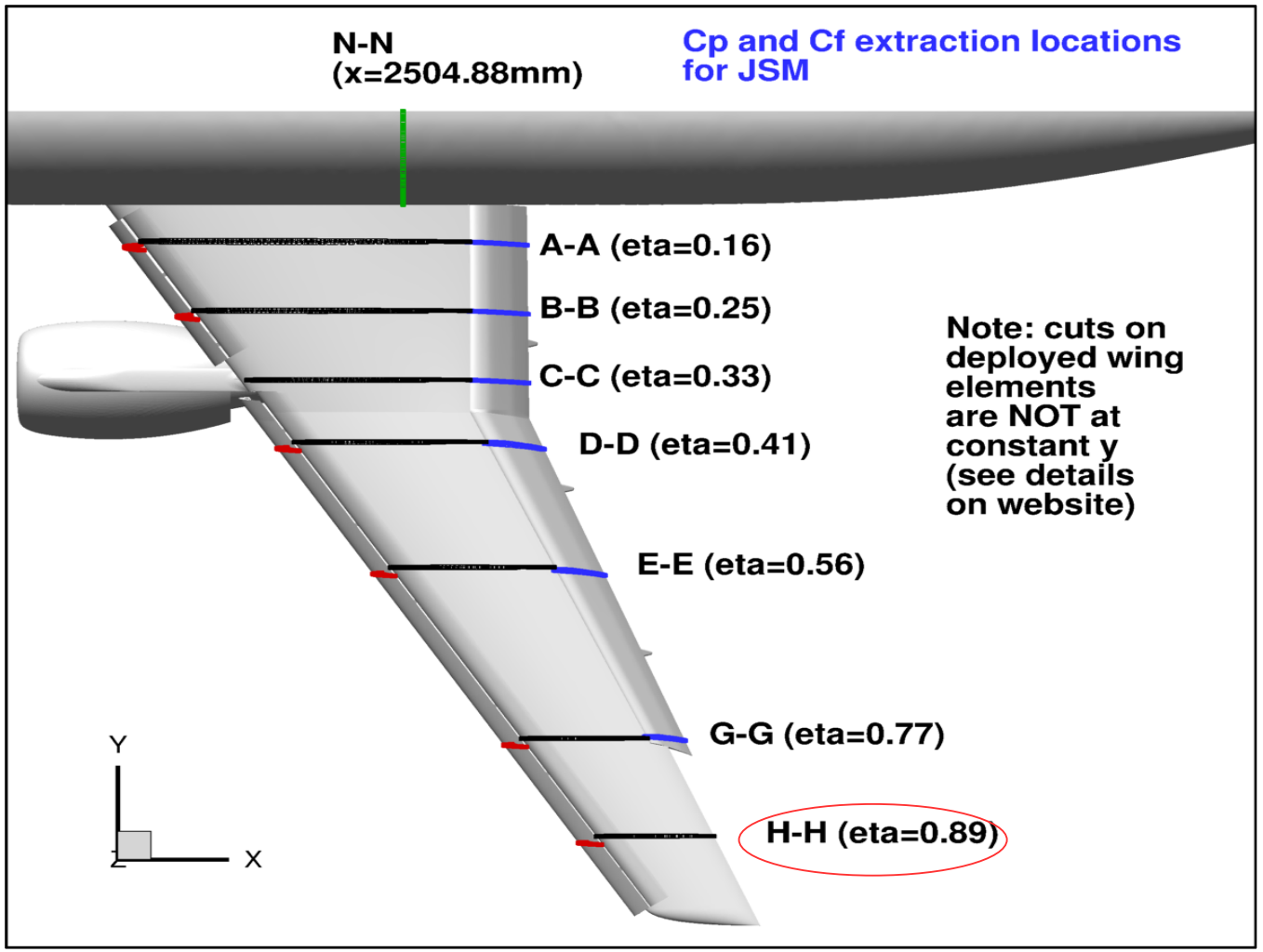


AOA = 21.59 deg



CASE 2a - WB
Comparison of CP distribution

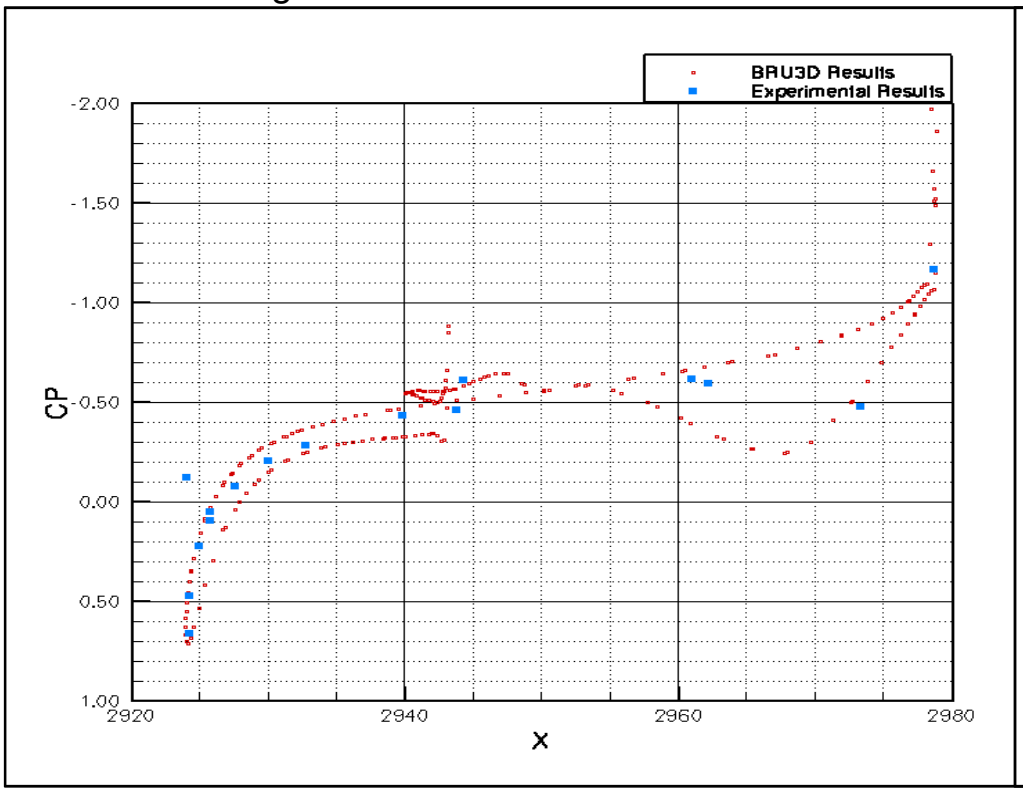
- Postprocessing: Surface Data Extraction for JSM (Case 2)



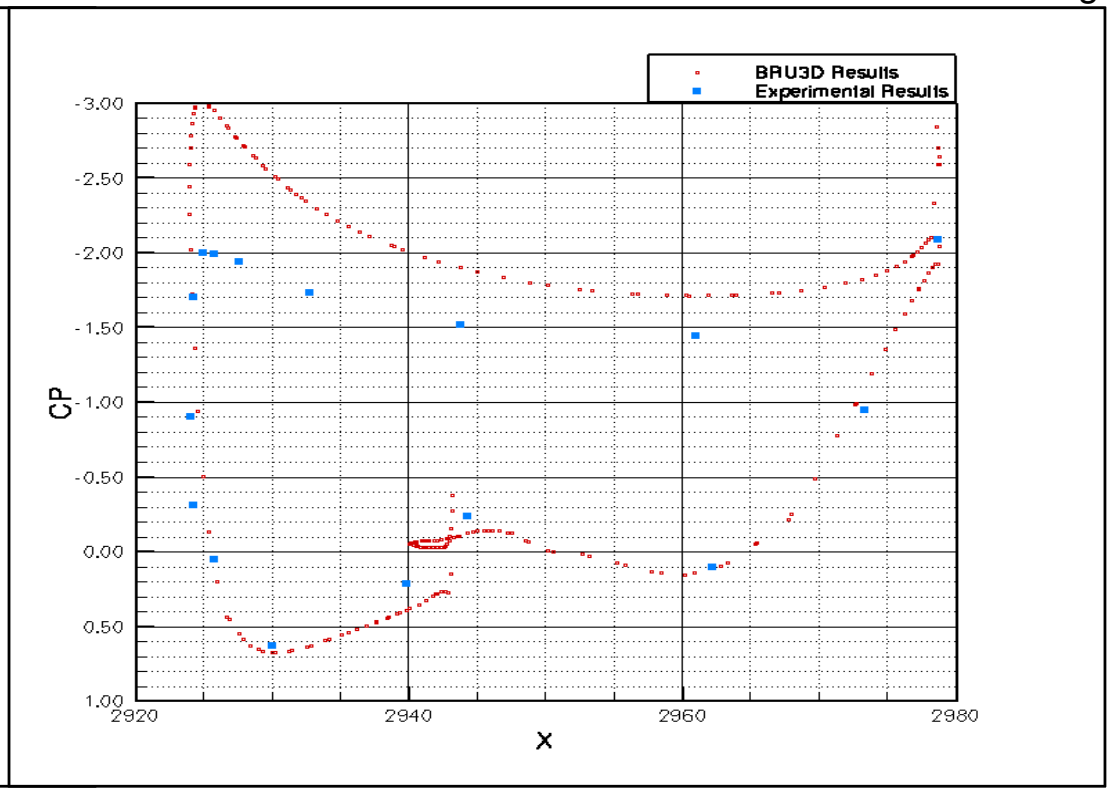
CASE 2a - WB
Comparison of CP distribution

- WB – SLAT H - H

AOA = 4.36 deg



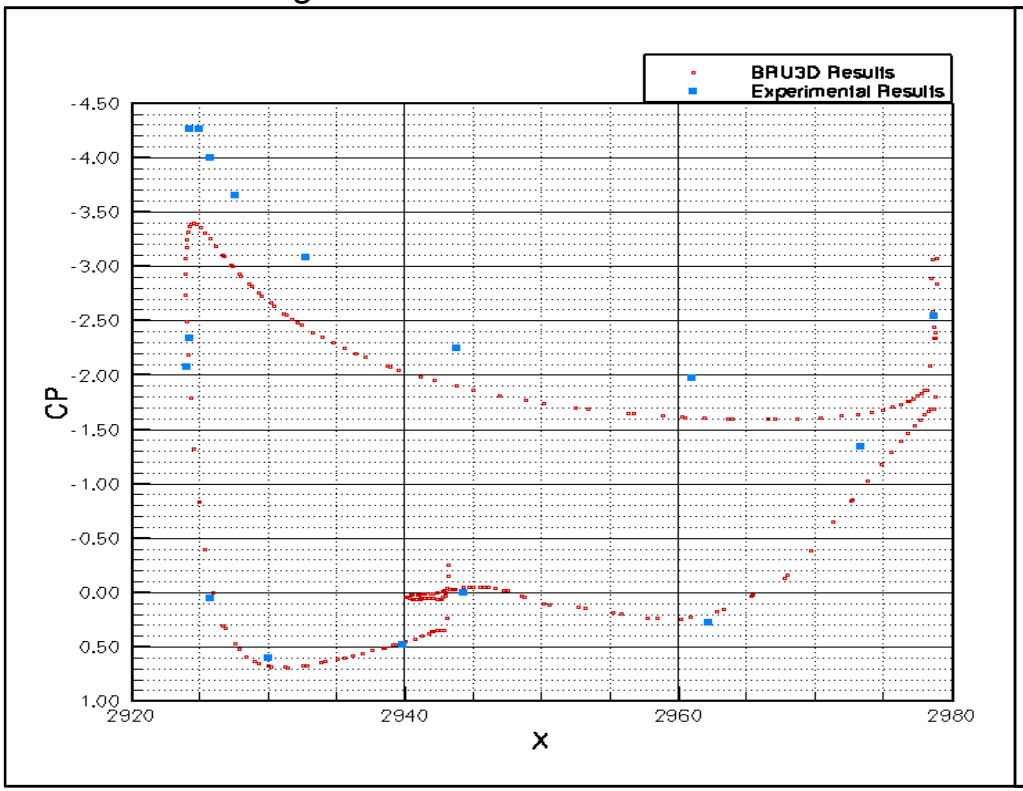
AOA = 10.47 deg



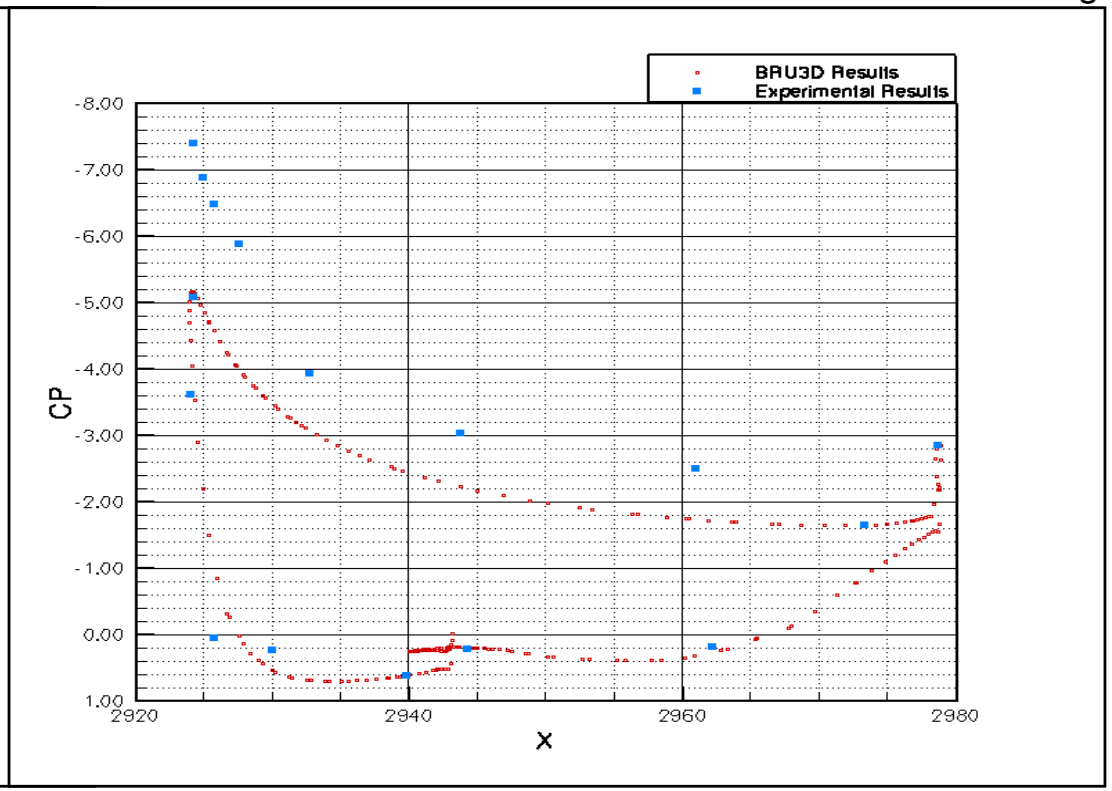
CASE 2a - WB
Comparison of CP distribution

- WB – SLAT H - H

AOA = 14.54 deg



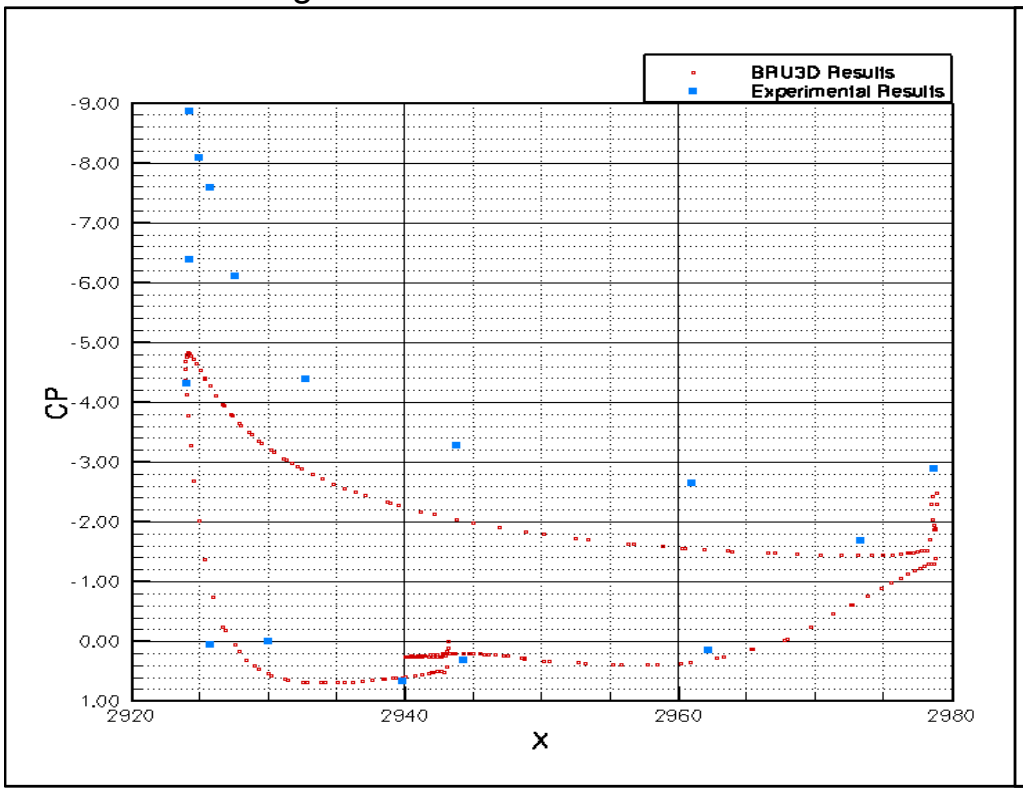
AOA = 18.58 deg



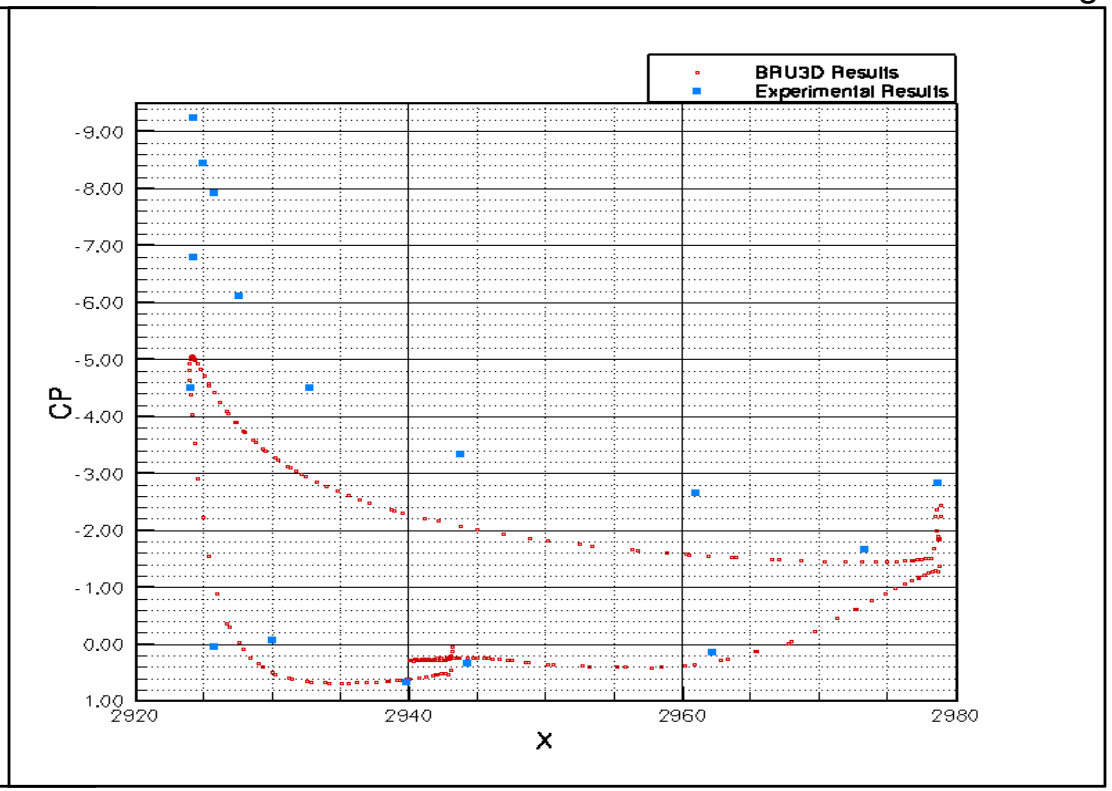
CASE 2a - WB
Comparison of CP distribution

- WB – SLAT H – H

AOA = 20.57 deg



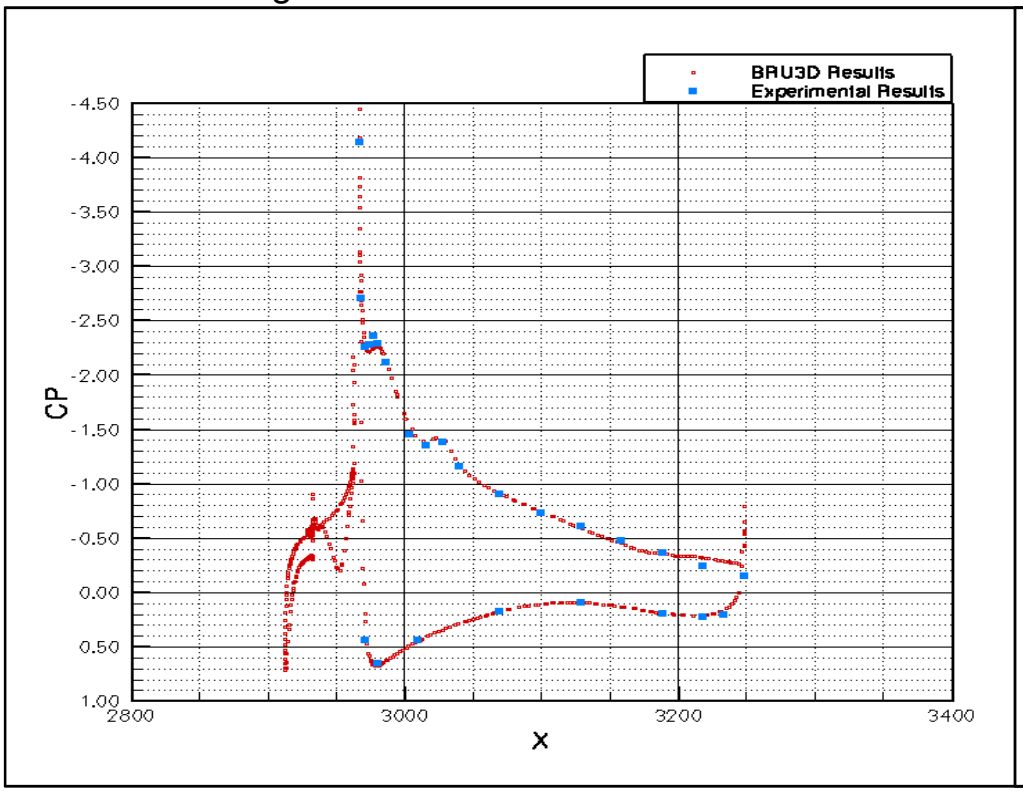
AOA = 21.59 deg



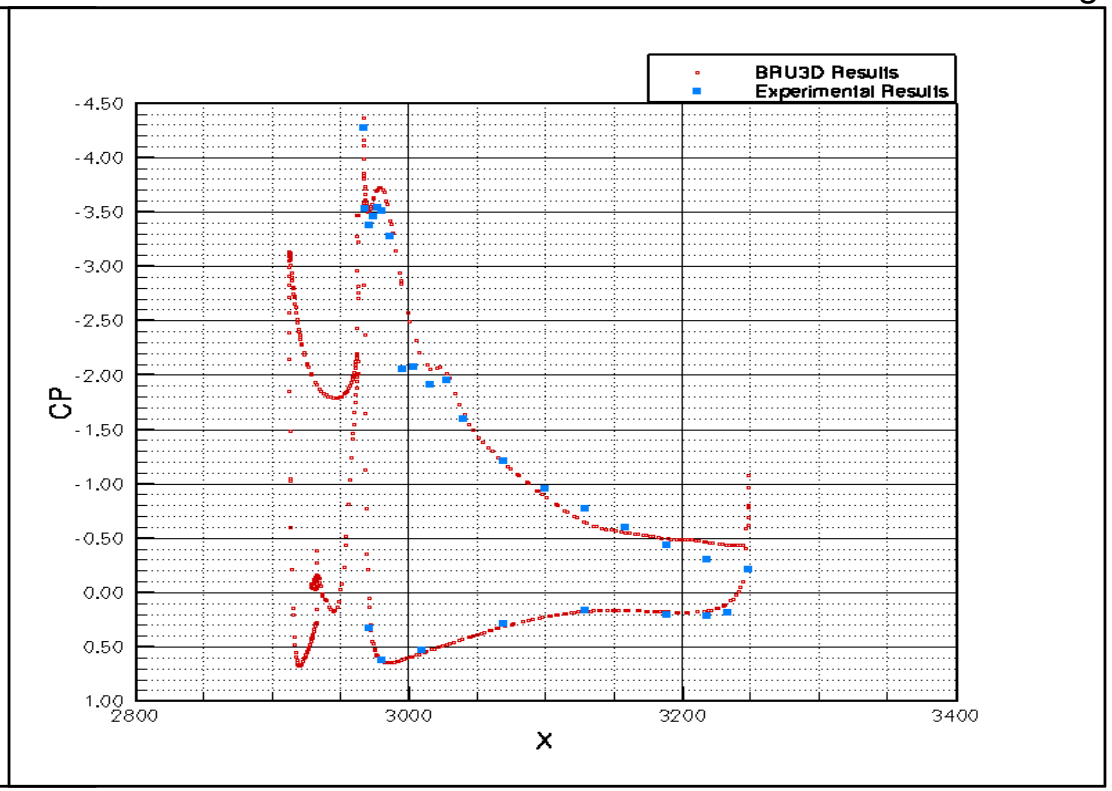
CASE 2a - WB
Comparison of CP distribution

- WB – MAIN ELEMENT B – B

AOA = 4.36 deg



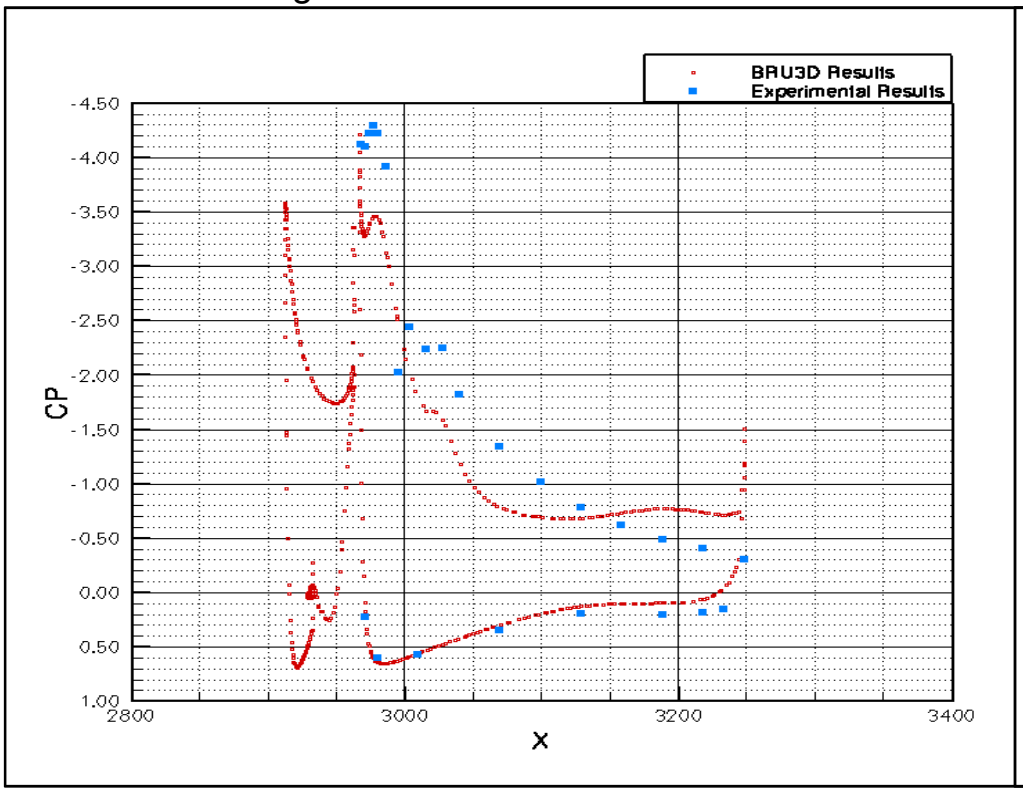
AOA = 10.47 deg



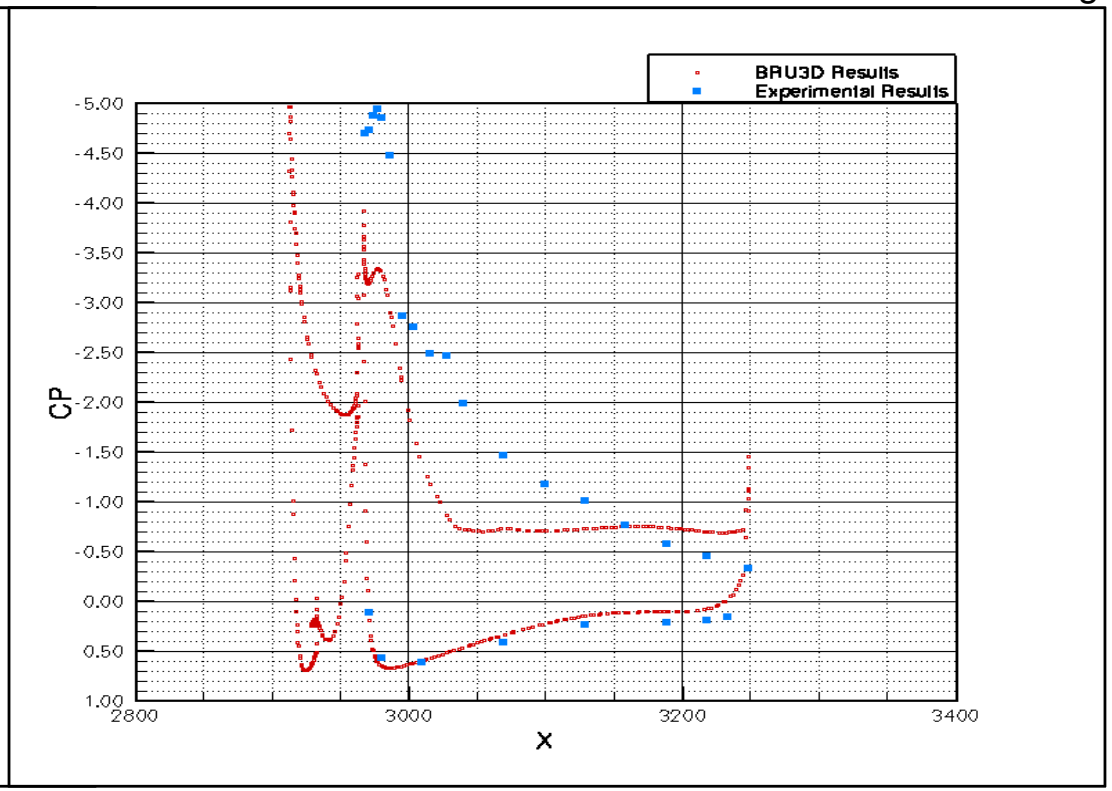
CASE 2a - WB
Comparison of CP distribution

- WB – MAIN ELEMENT H – H

AOA = 14.54 deg



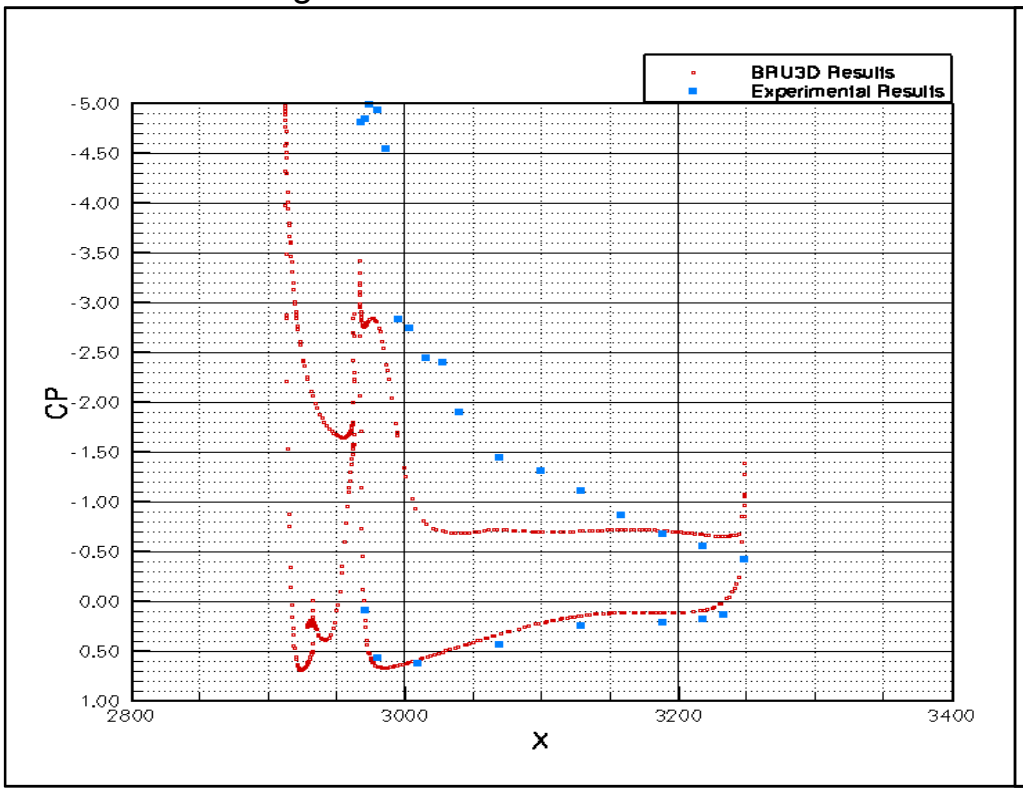
AOA = 18.58 deg



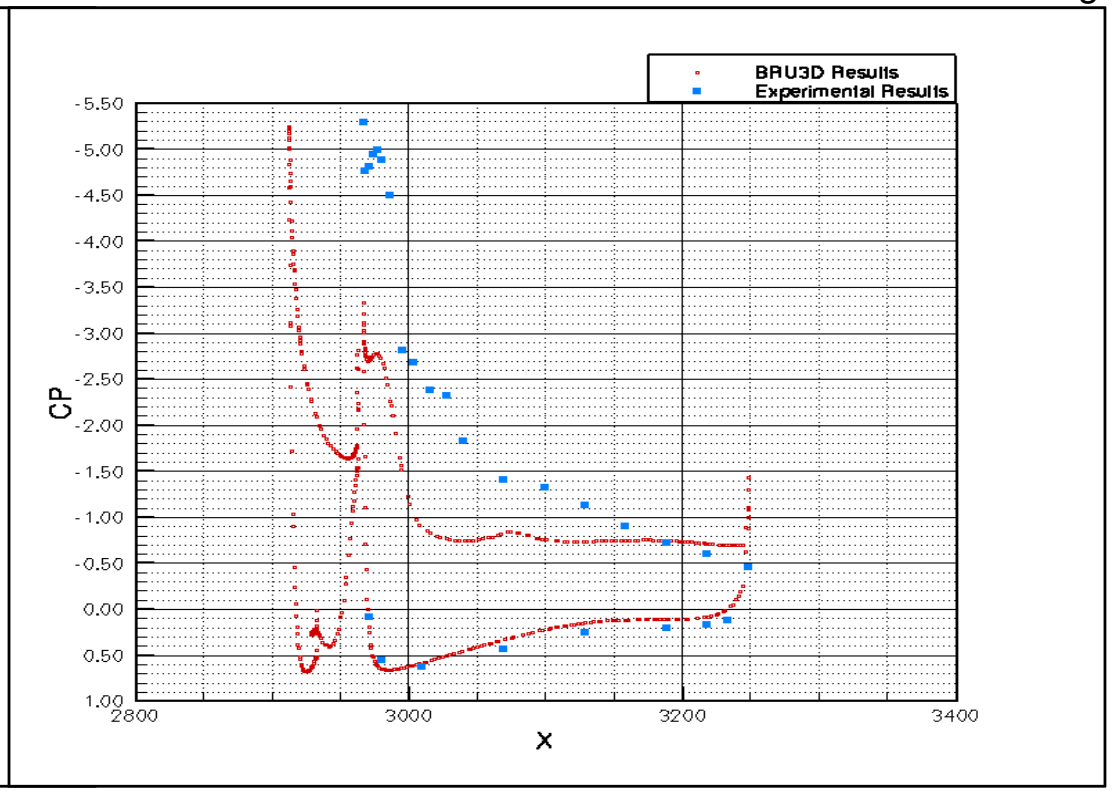
CASE 2a - WB
Comparison of CP distribution

- WB – MAIN ELEMENT H – H

AOA = 20.57 deg

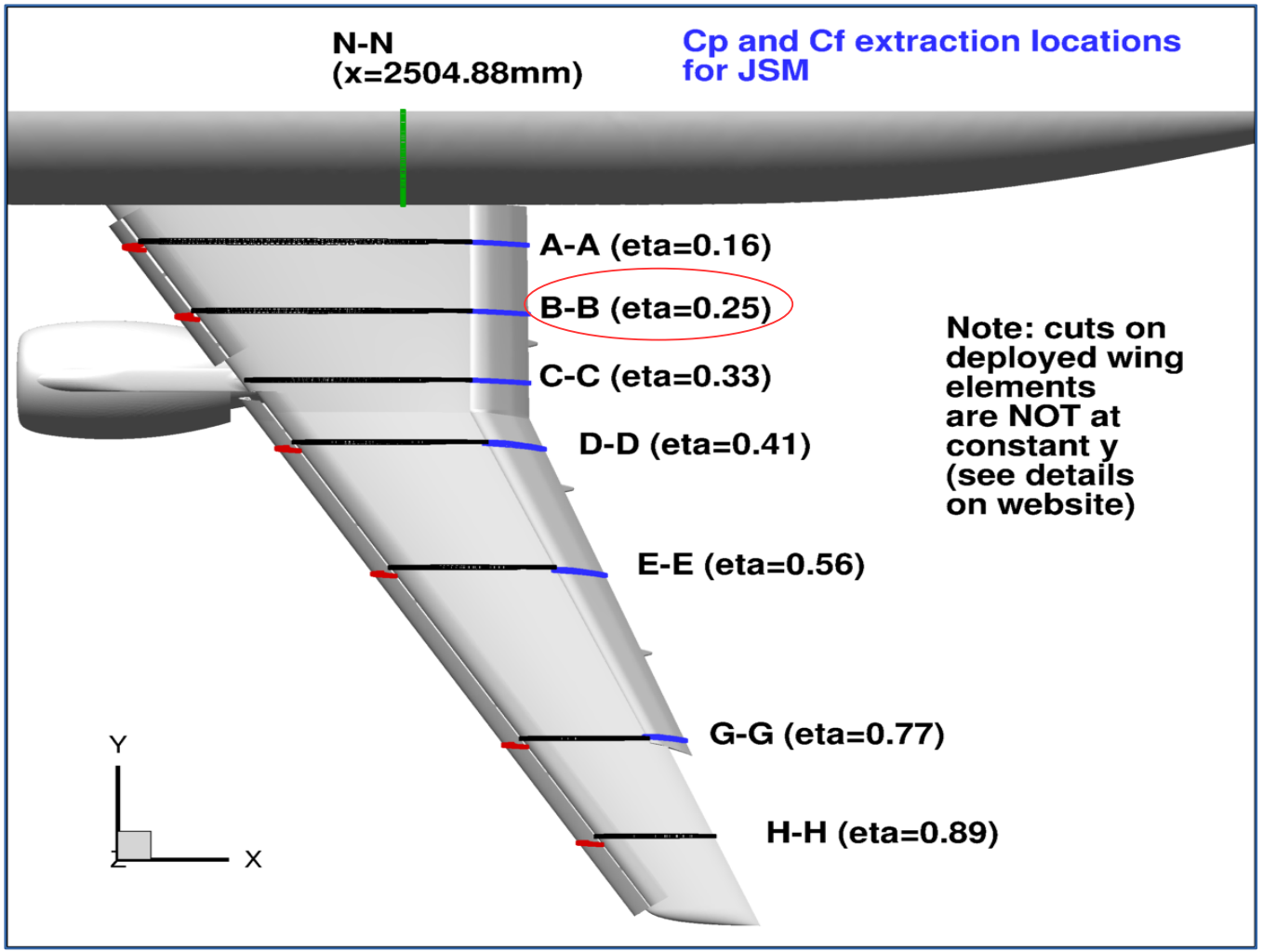


AOA = 21.59 deg



CASE 2c - WBPN
Comparison of CP distribution

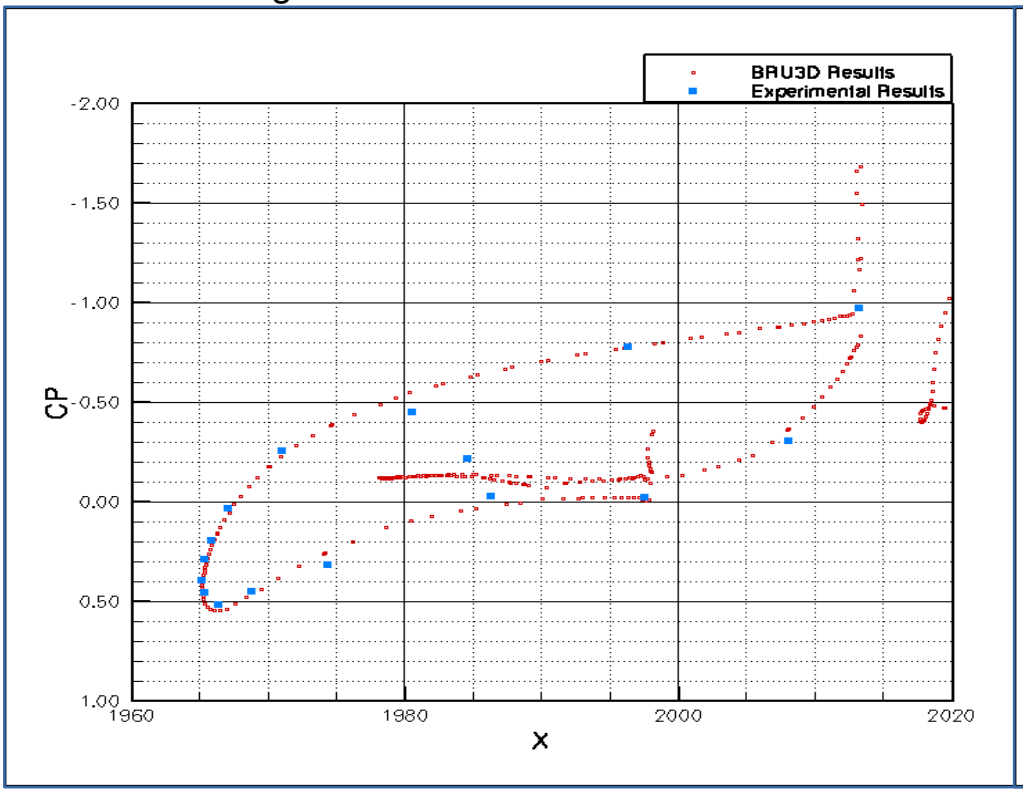
- Postprocessing: Surface Data Extraction for JSM (Case 2)



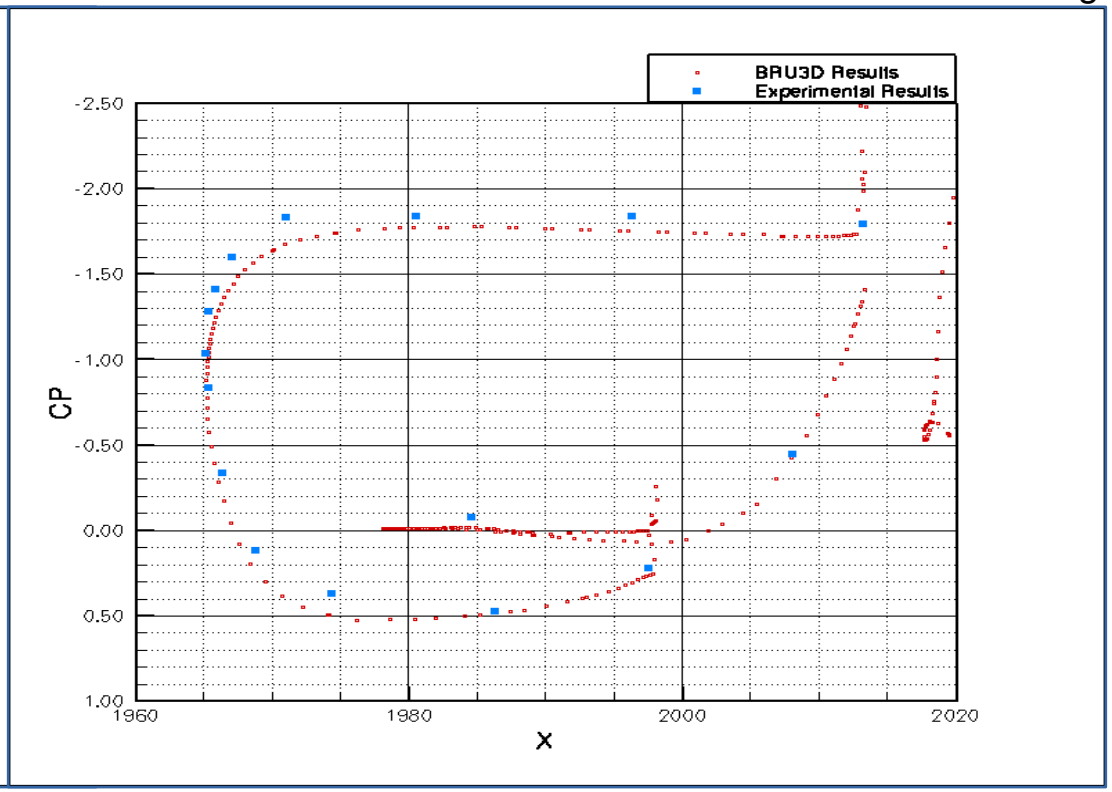
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – SLAT B – B

AOA = 4.36 deg



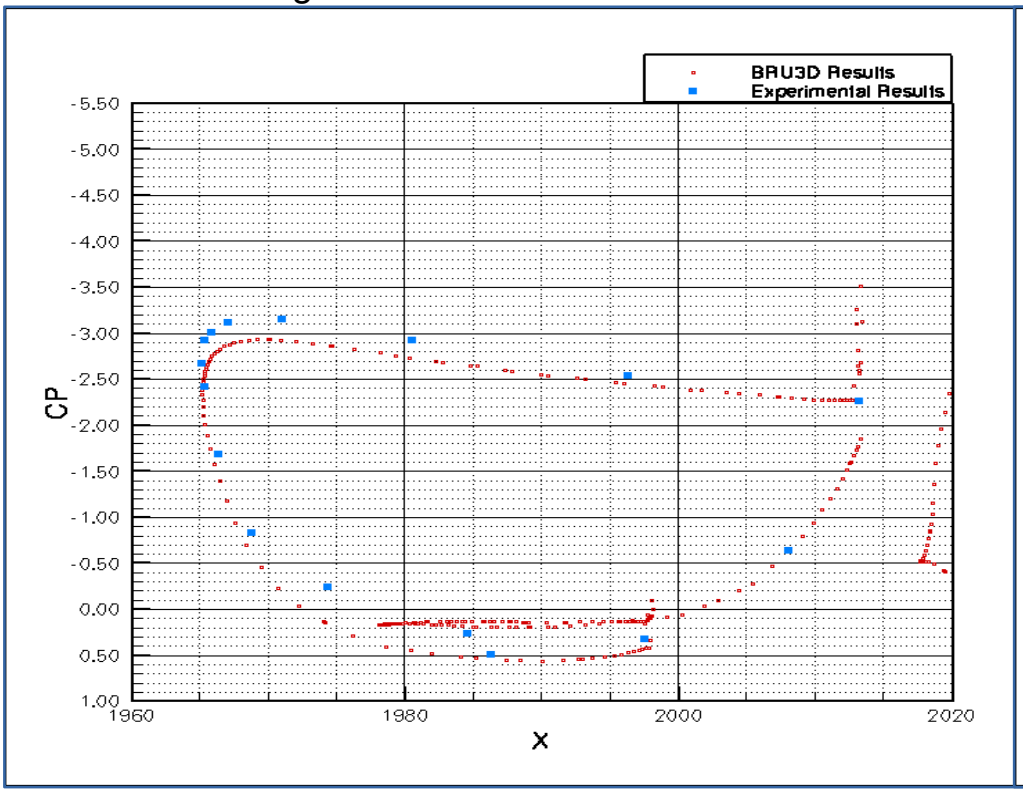
AOA = 10.47 deg



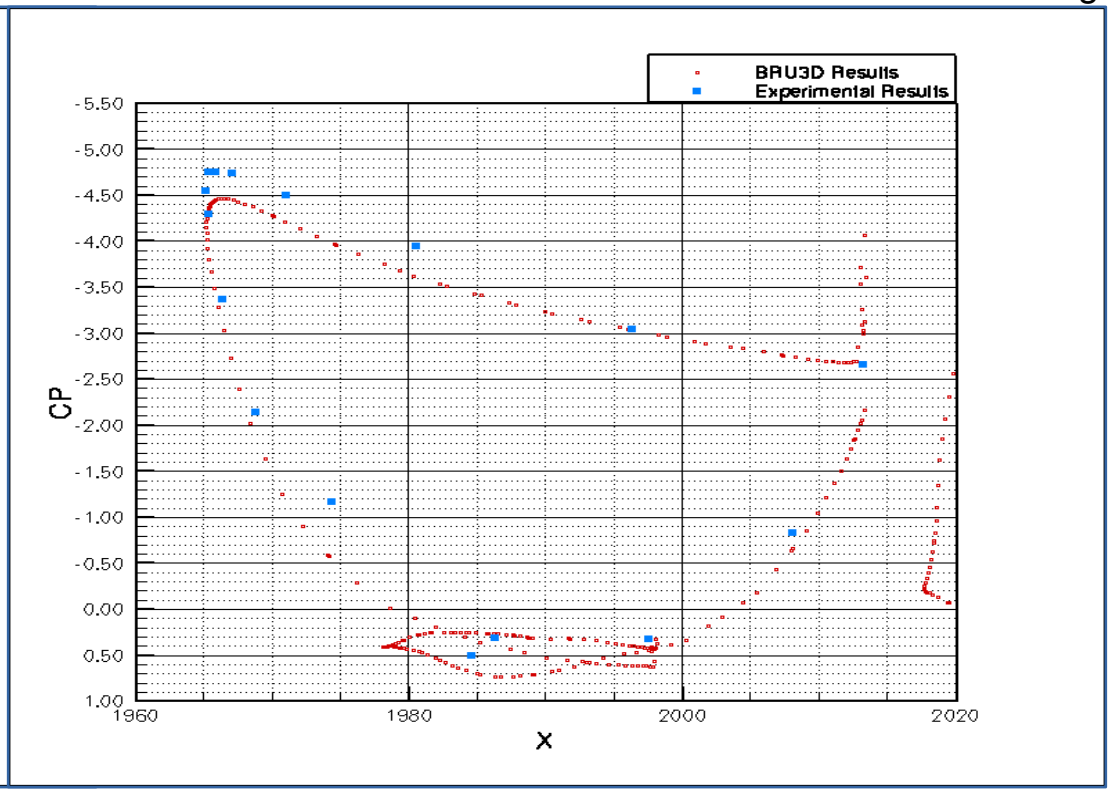
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – SLAT B – B

AOA = 14.54 deg



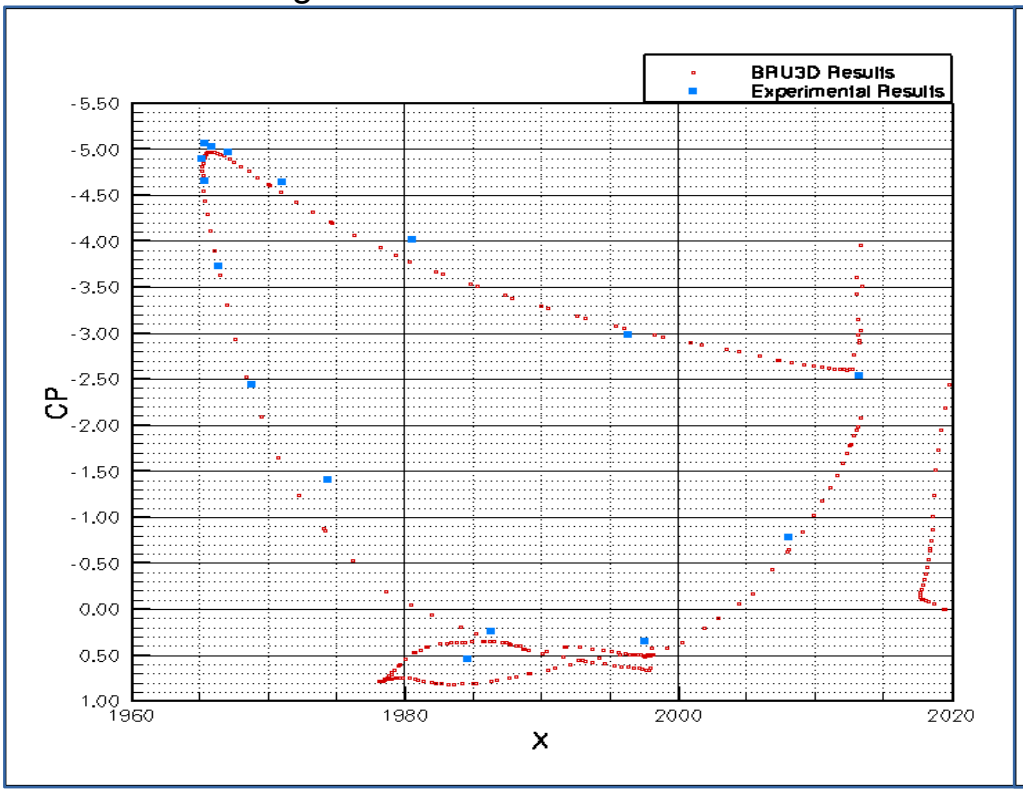
AOA = 18.58 deg



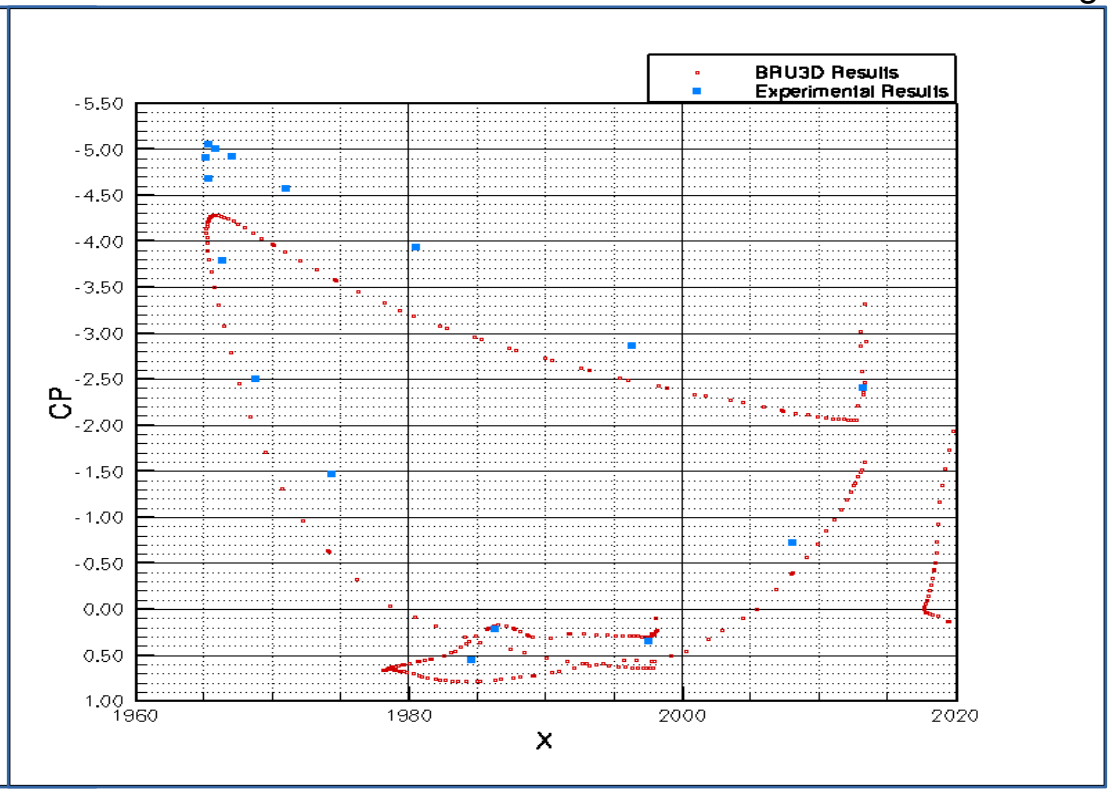
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – SLAT B – B

AOA = 20.57 deg



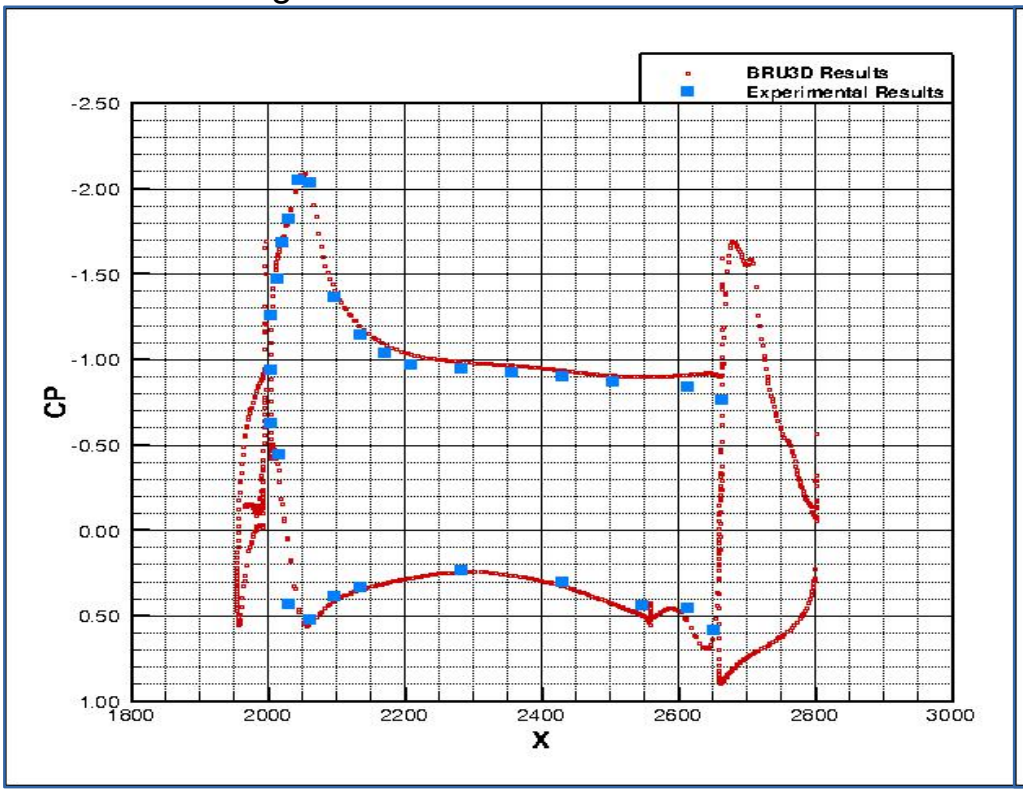
AOA = 21.59 deg



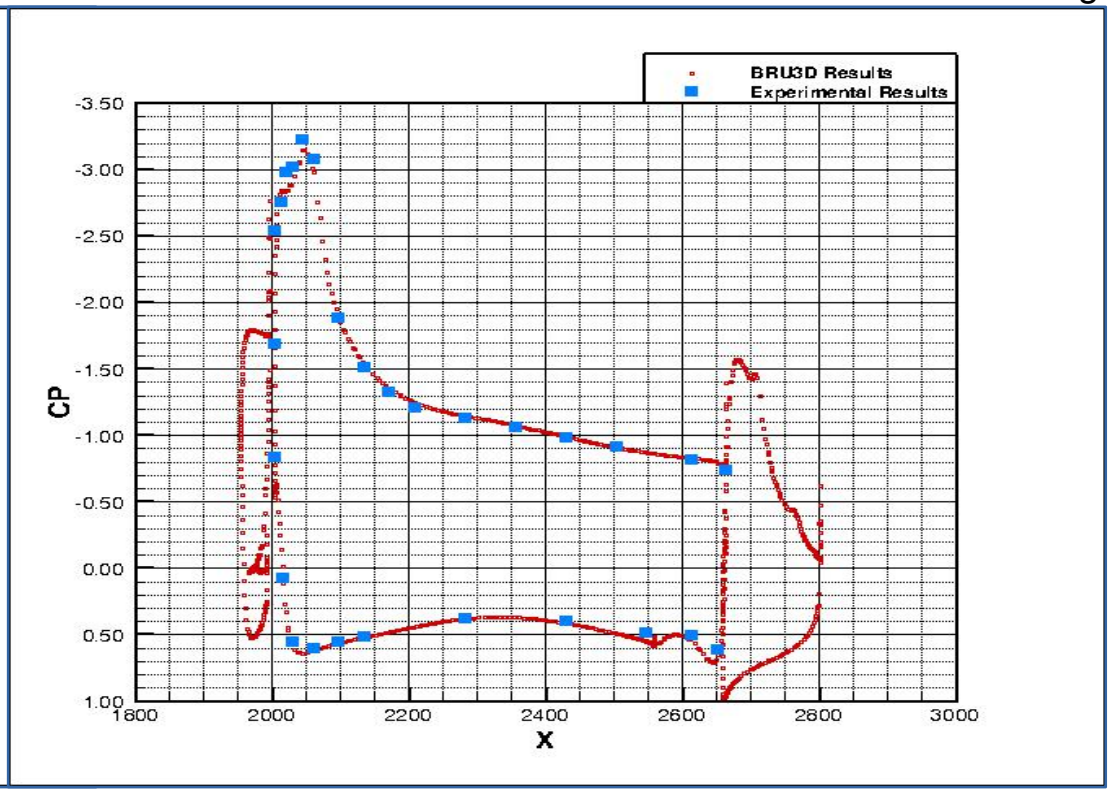
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – MAIN ELEMENT B – B

AOA = 4.36 deg



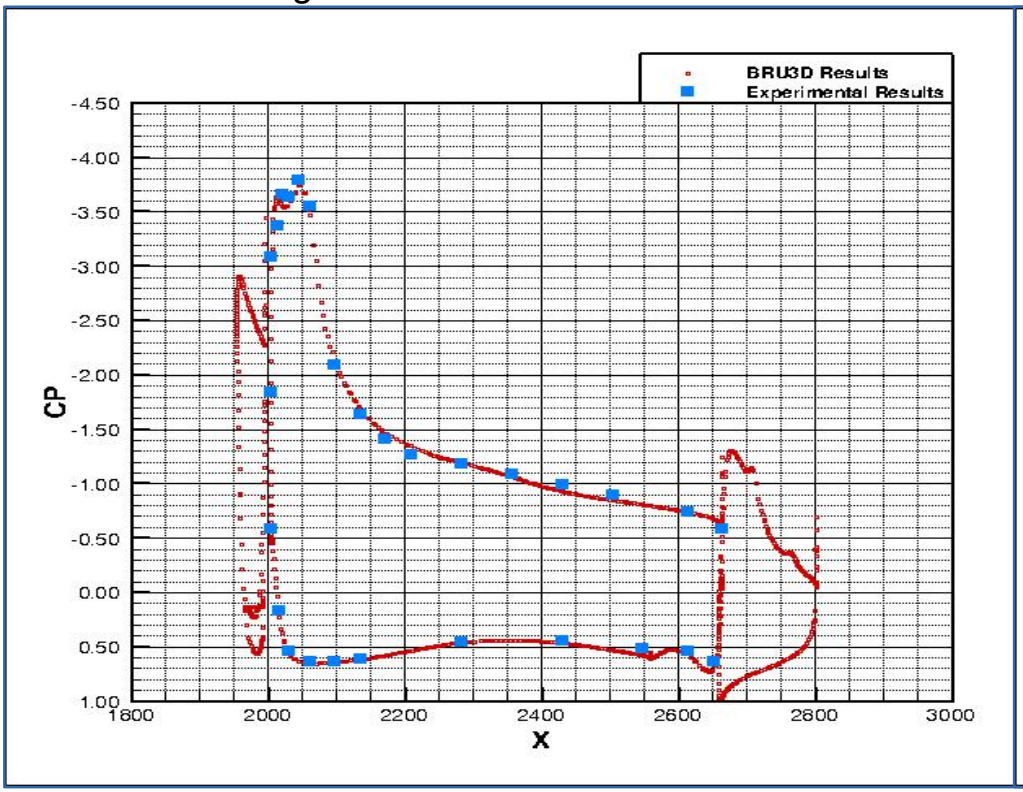
AOA = 10.47 deg



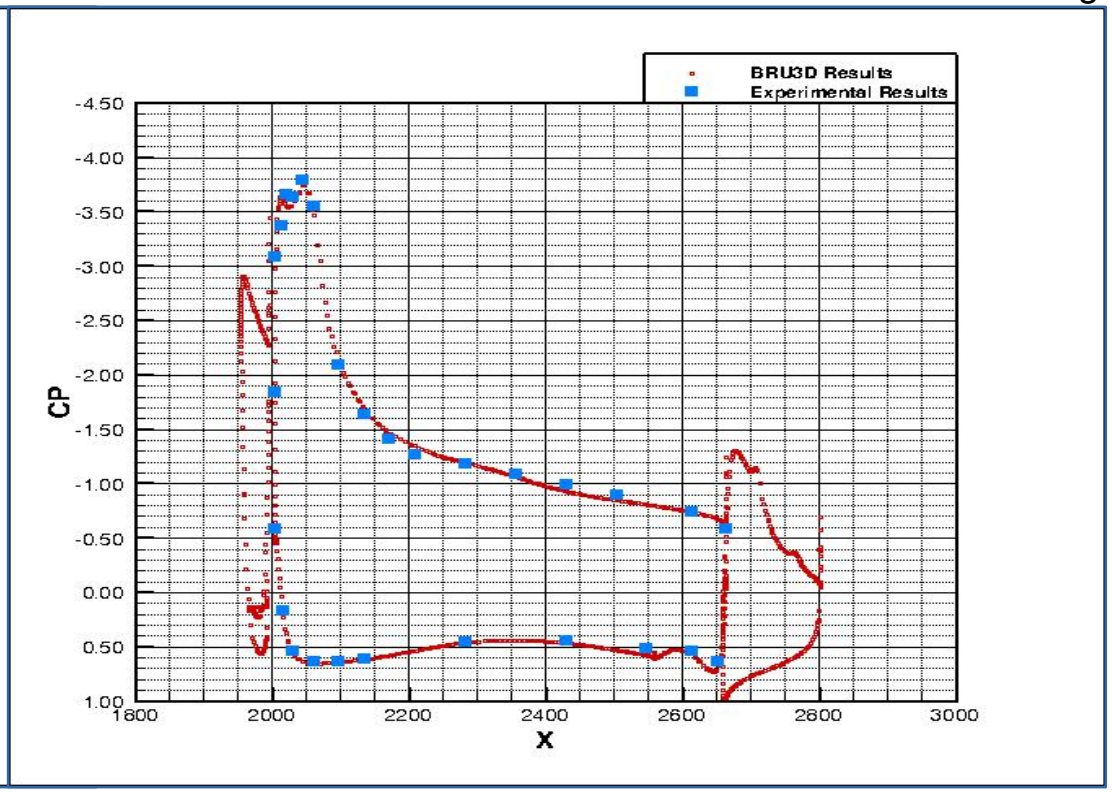
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – MAIN ELEMENT B – B

AOA = 14.54 deg



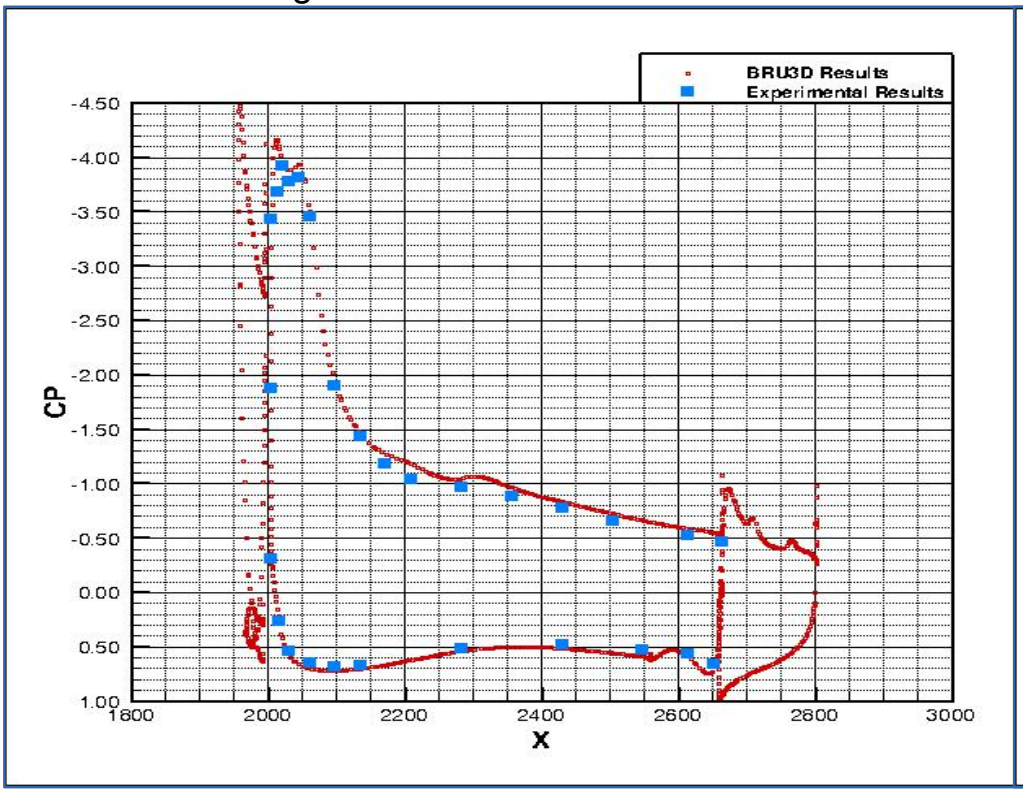
AOA = 18.58 deg



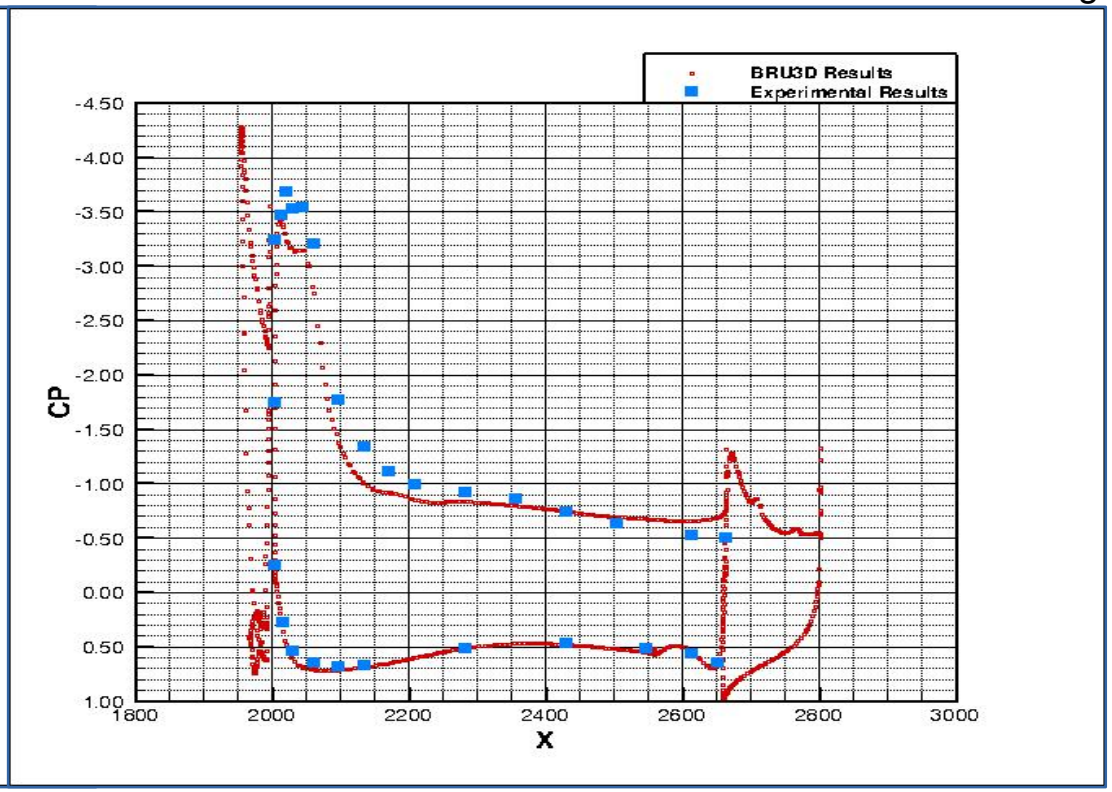
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – MAIN ELEMENT B – B

AOA = 20.57 deg



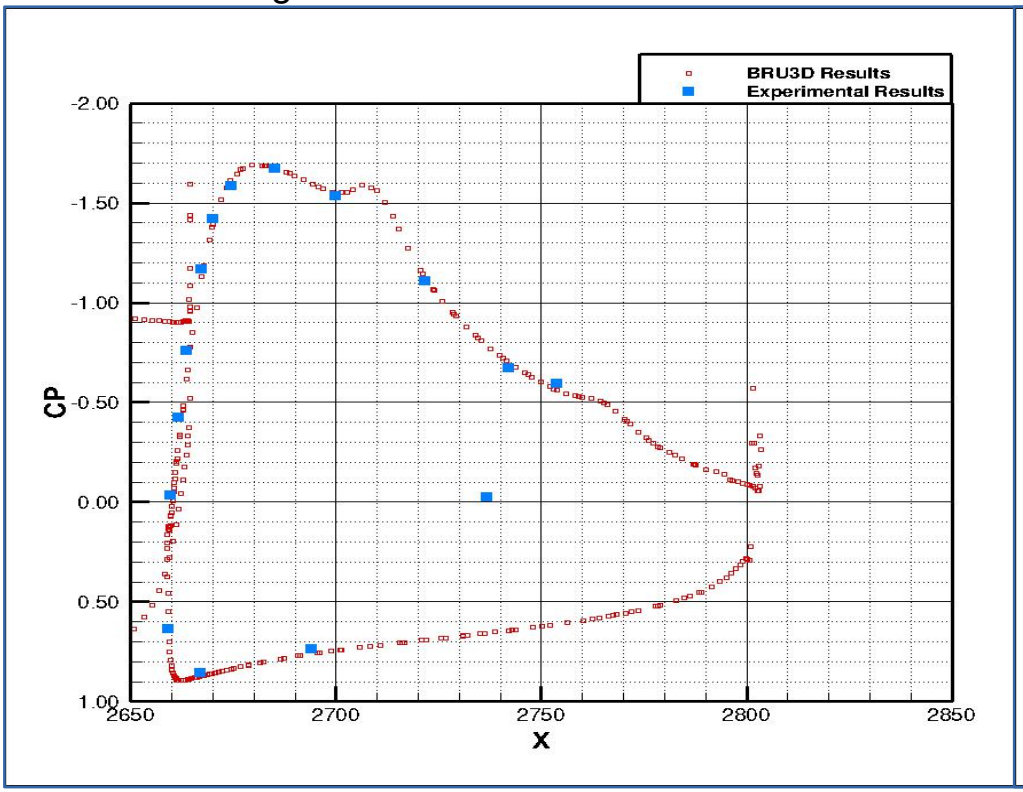
AOA = 21.59 deg



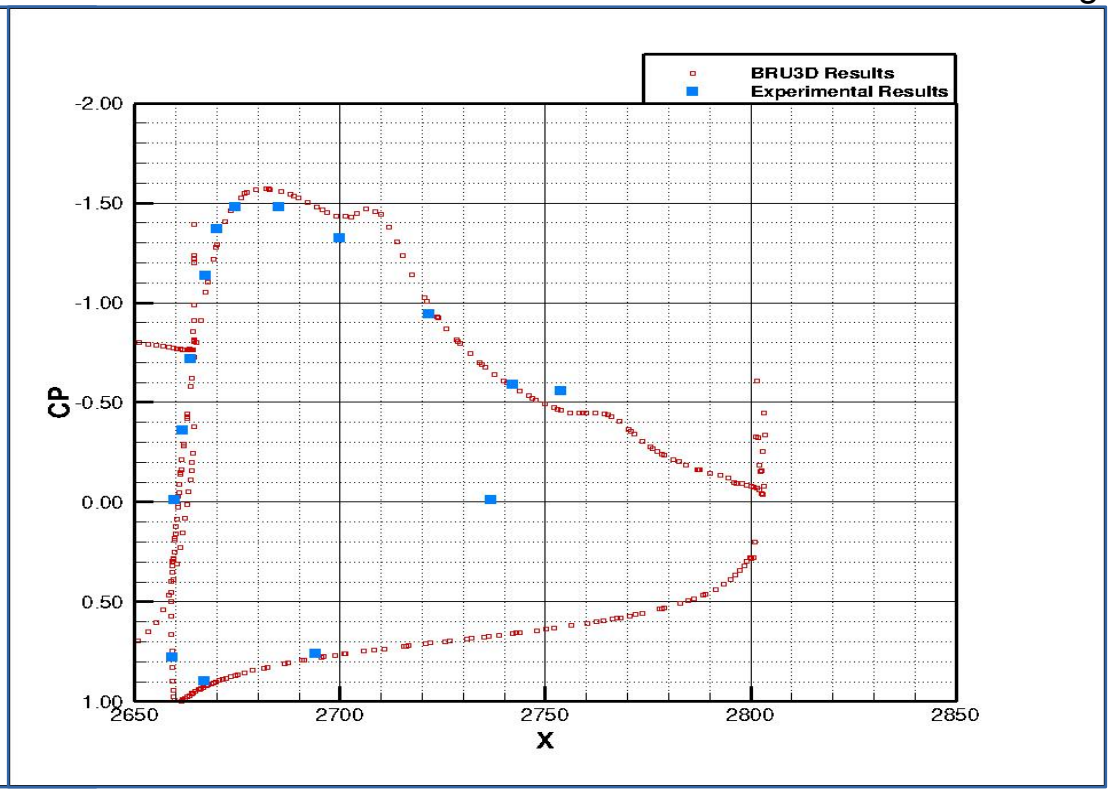
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – FLAP B – B

AOA = 4.36 deg



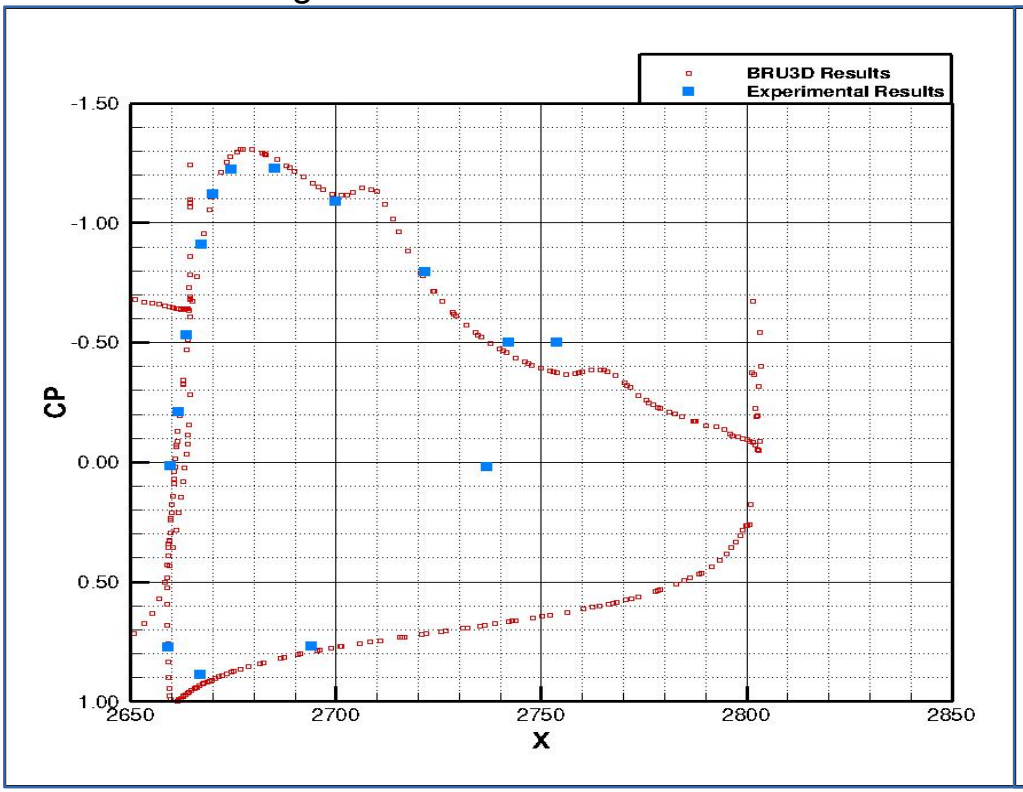
AOA = 10.47 deg



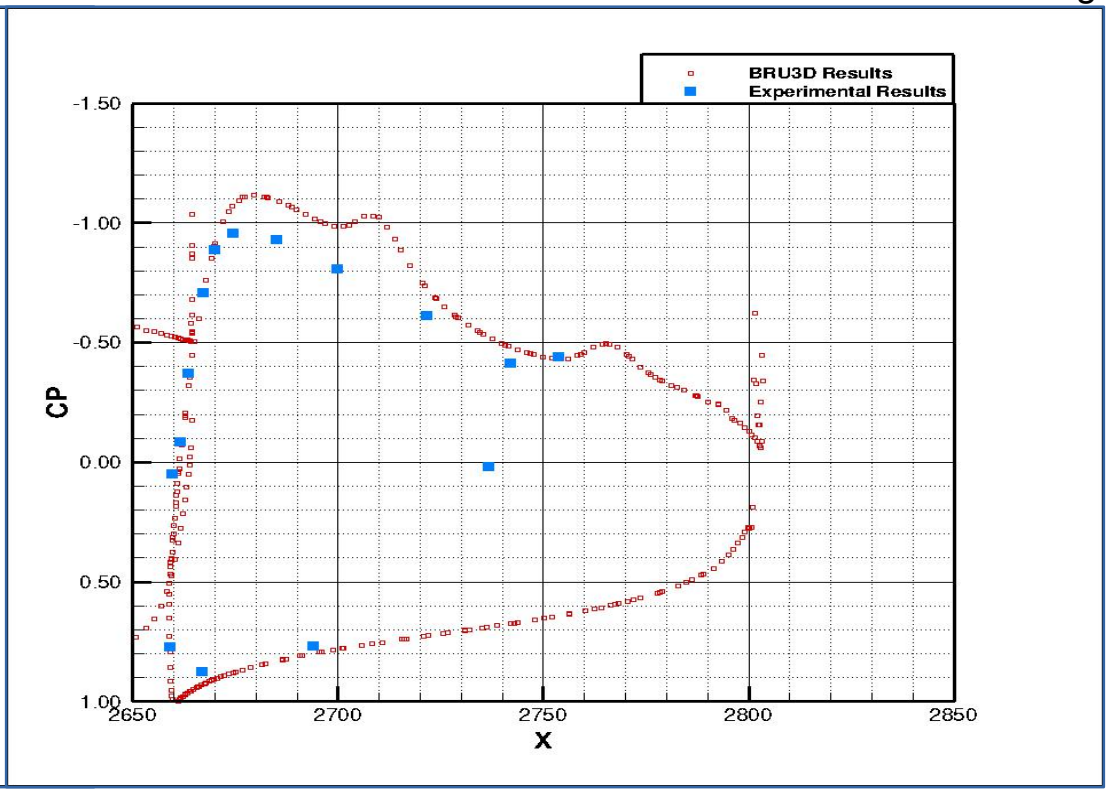
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – FLAP B – B

AOA = 14.54 deg



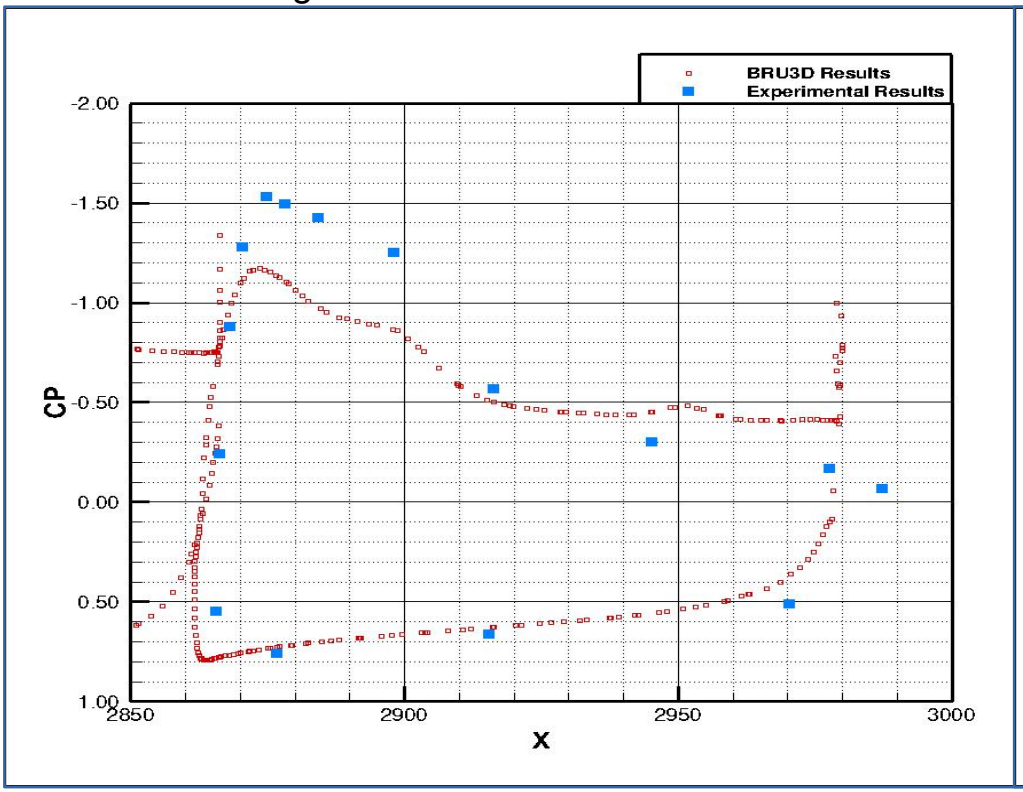
AOA = 18.58 deg



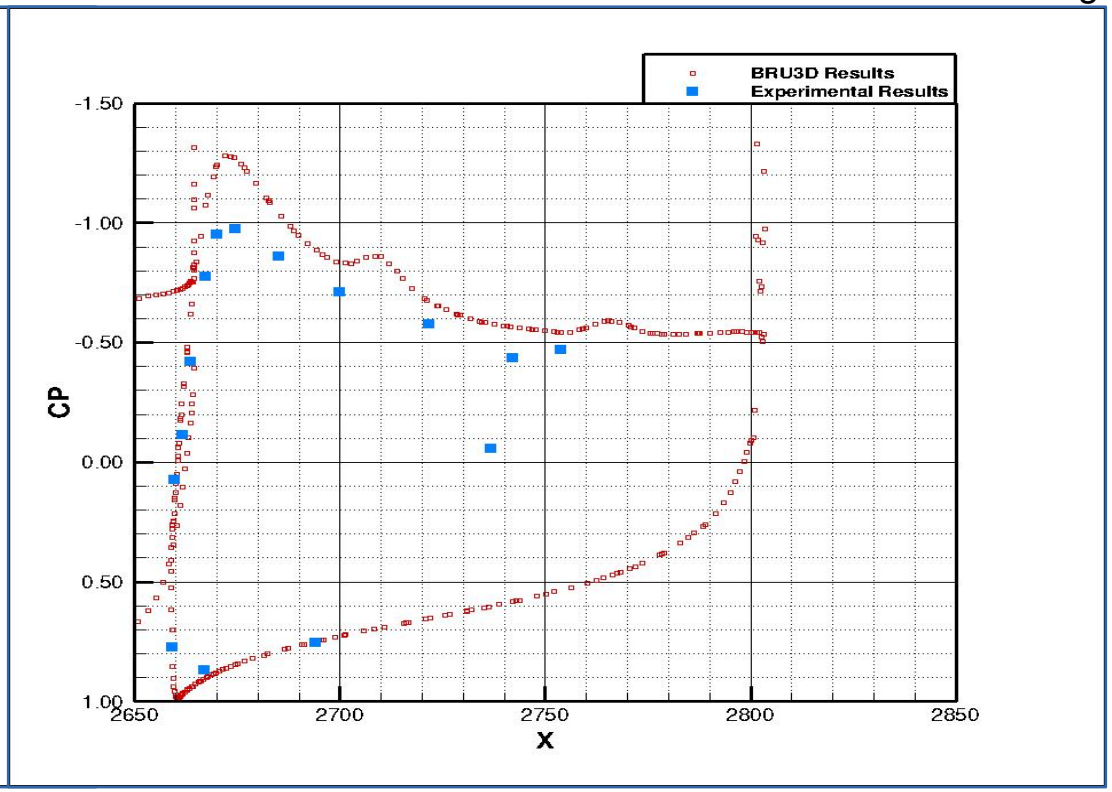
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – FLAP B – B

AOA = 20.57 deg

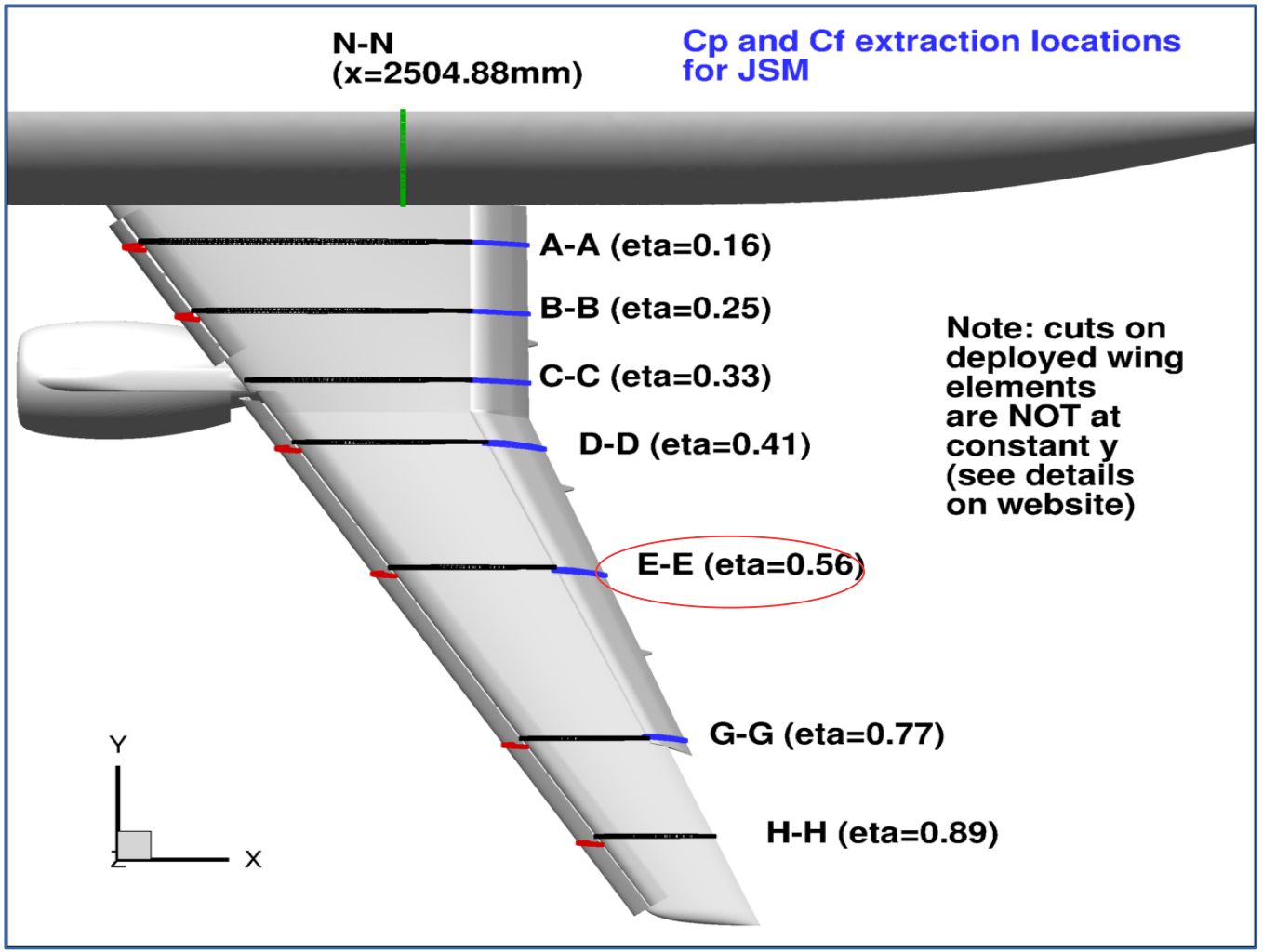


AOA = 21.59 deg



CASE 2c - WBPN
Comparison of CP distribution

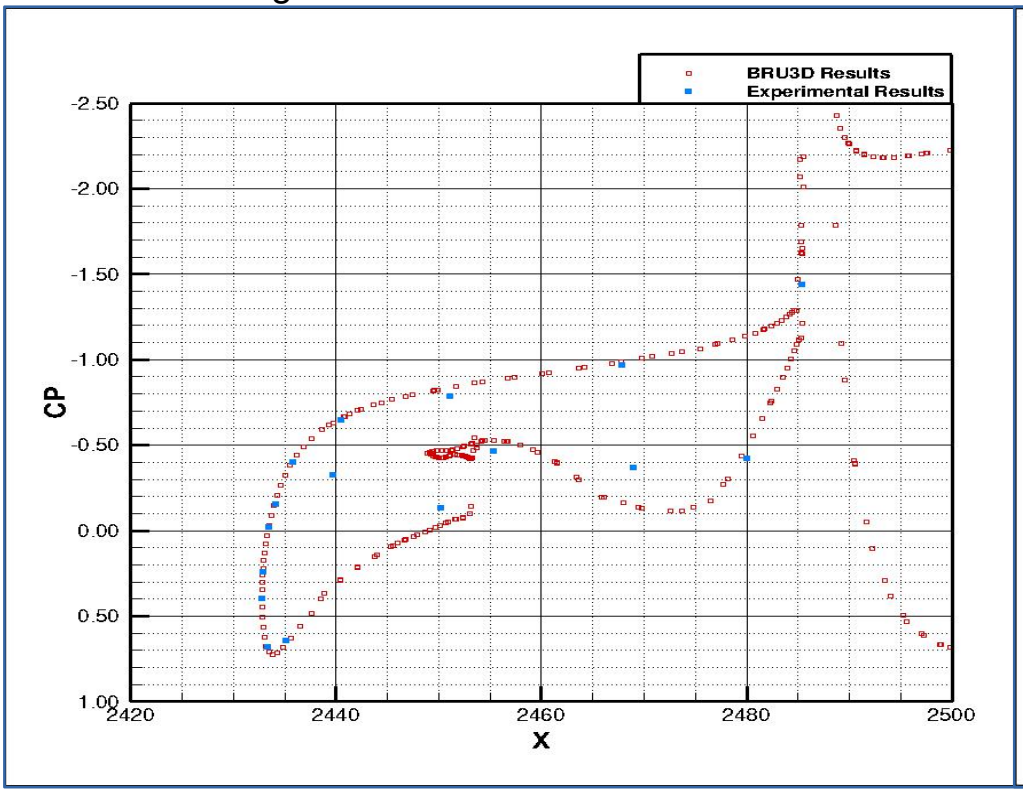
- Postprocessing: Surface Data Extraction for JSM (Case 2)



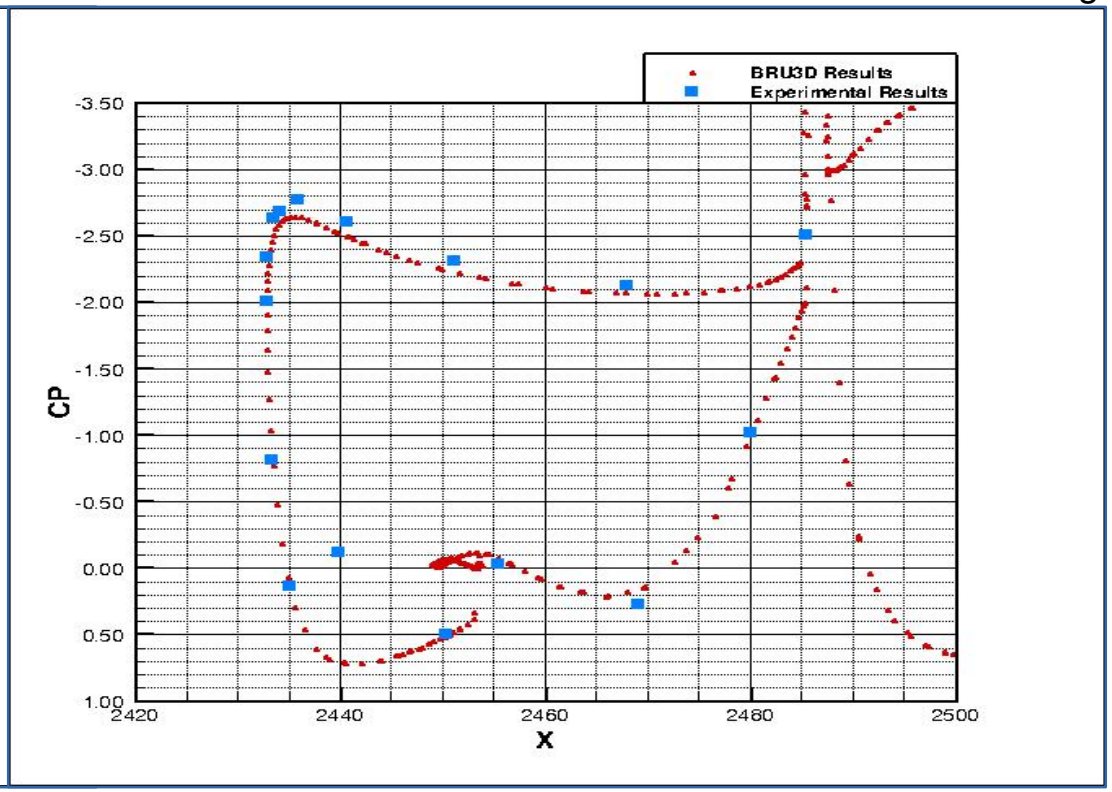
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – SLAT E - E

AOA = 4.36 deg



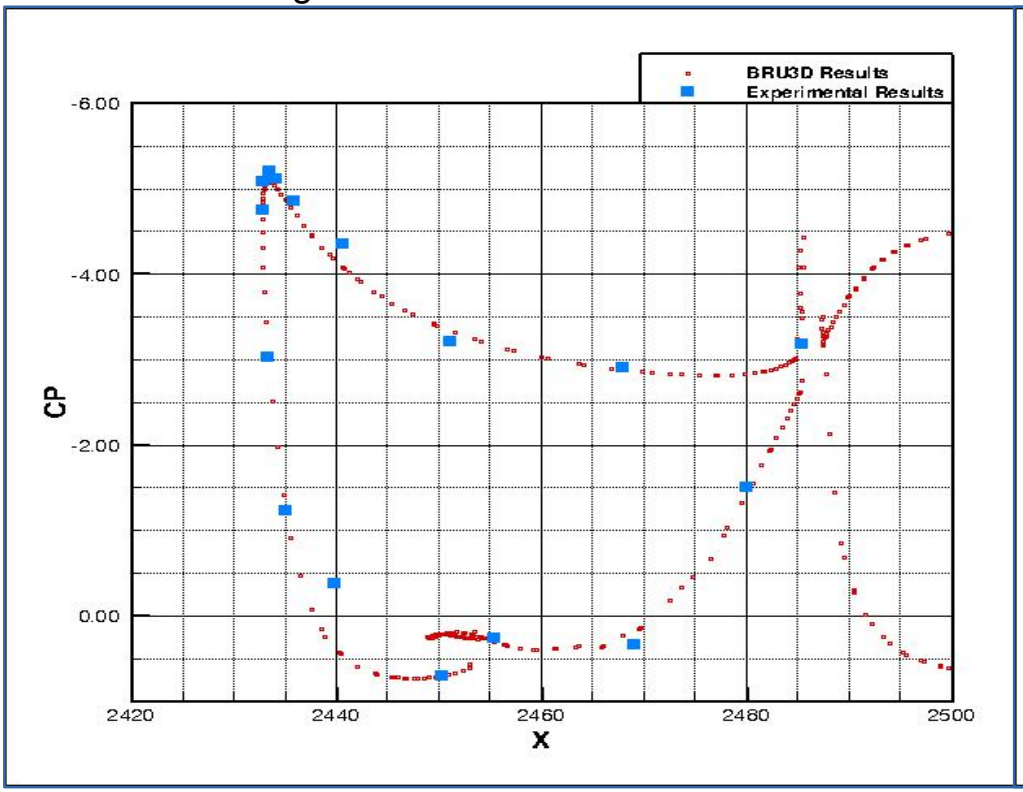
AOA = 10.47 deg



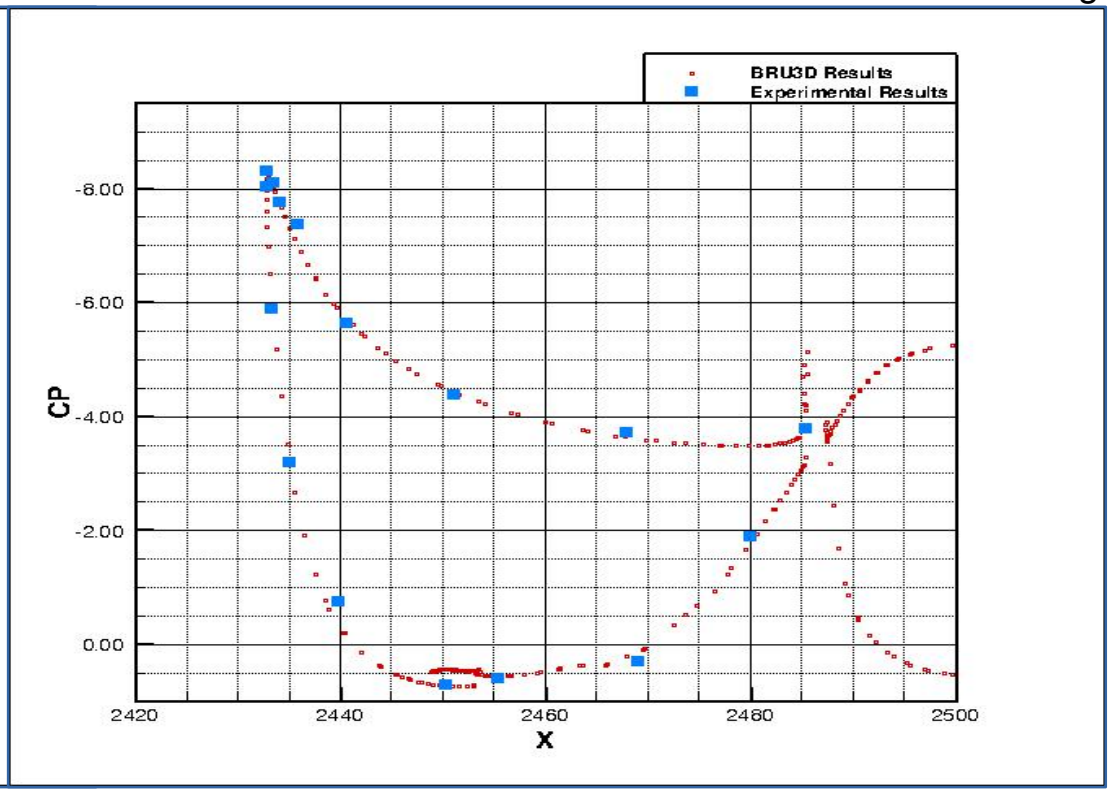
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – SLAT E - E

AOA = 14.54 deg



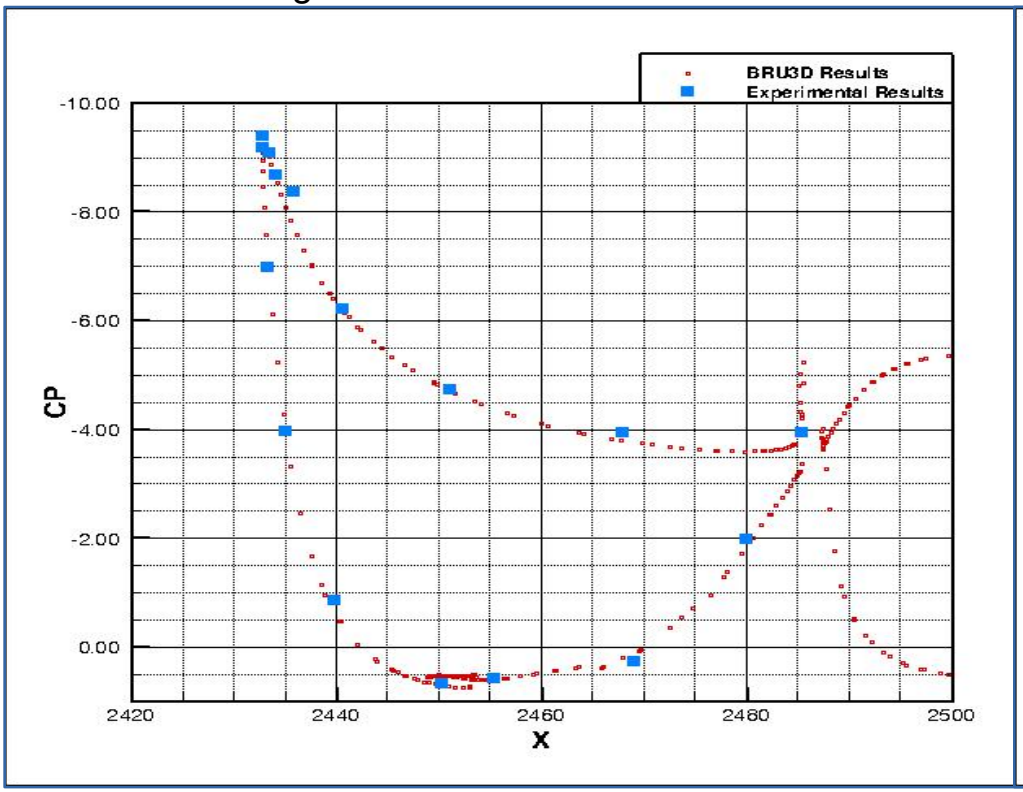
AOA = 18.58 deg



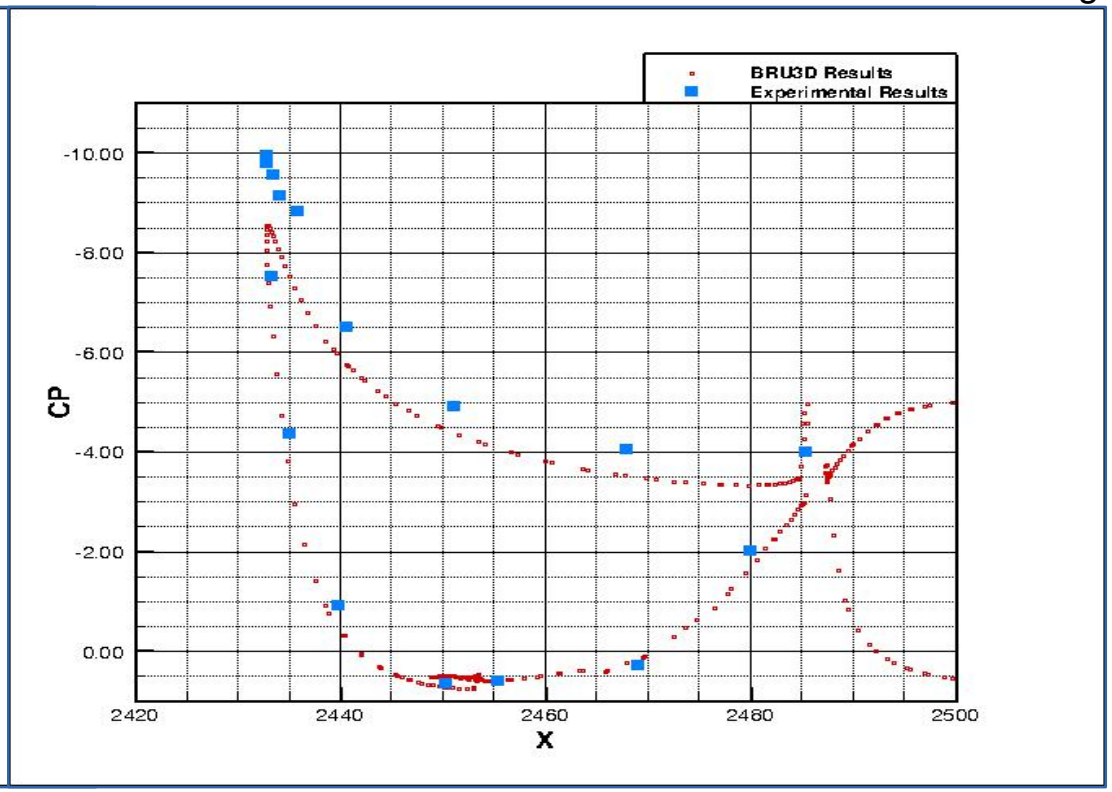
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – SLAT E - E

AOA = 20.57 deg



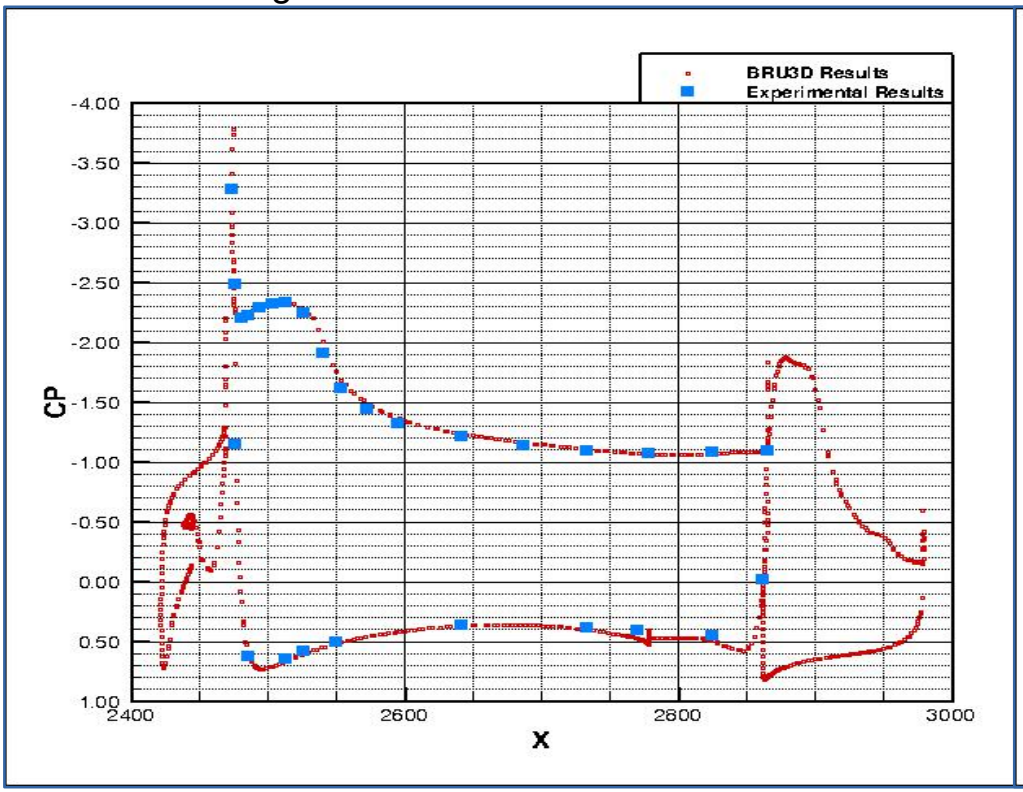
AOA = 21.59 deg



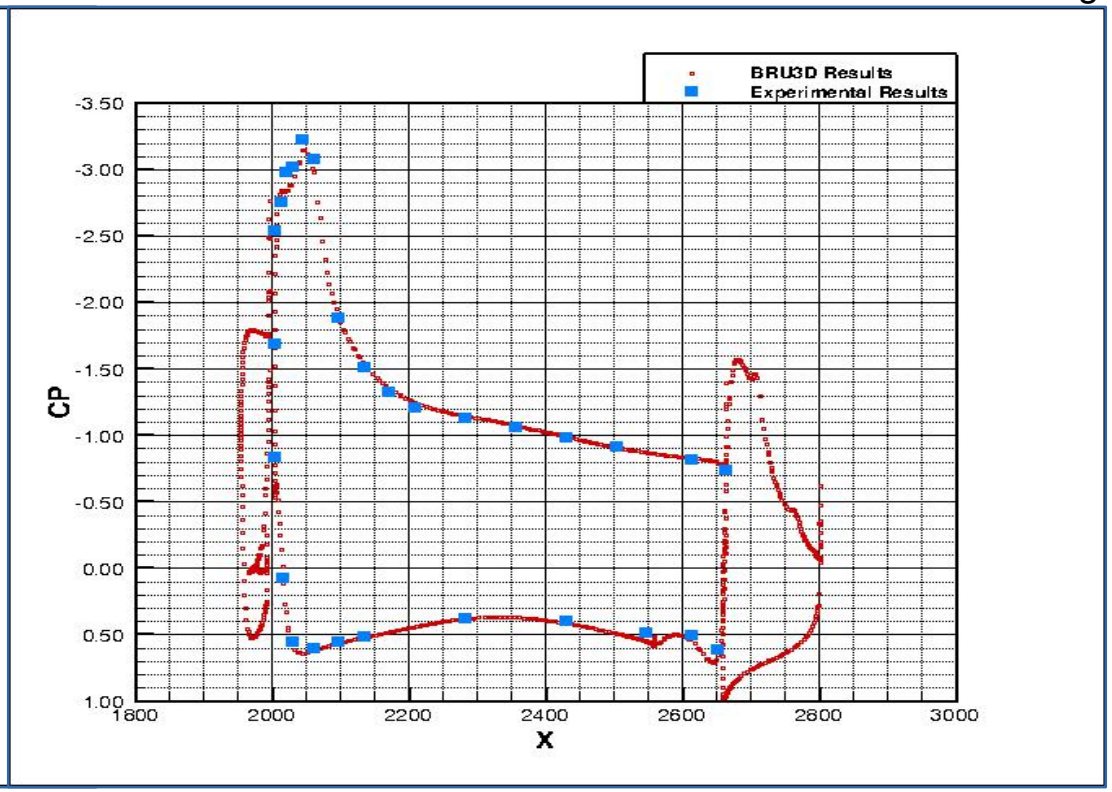
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – MAIN ELEMENT E - E

AOA = 4.36 deg



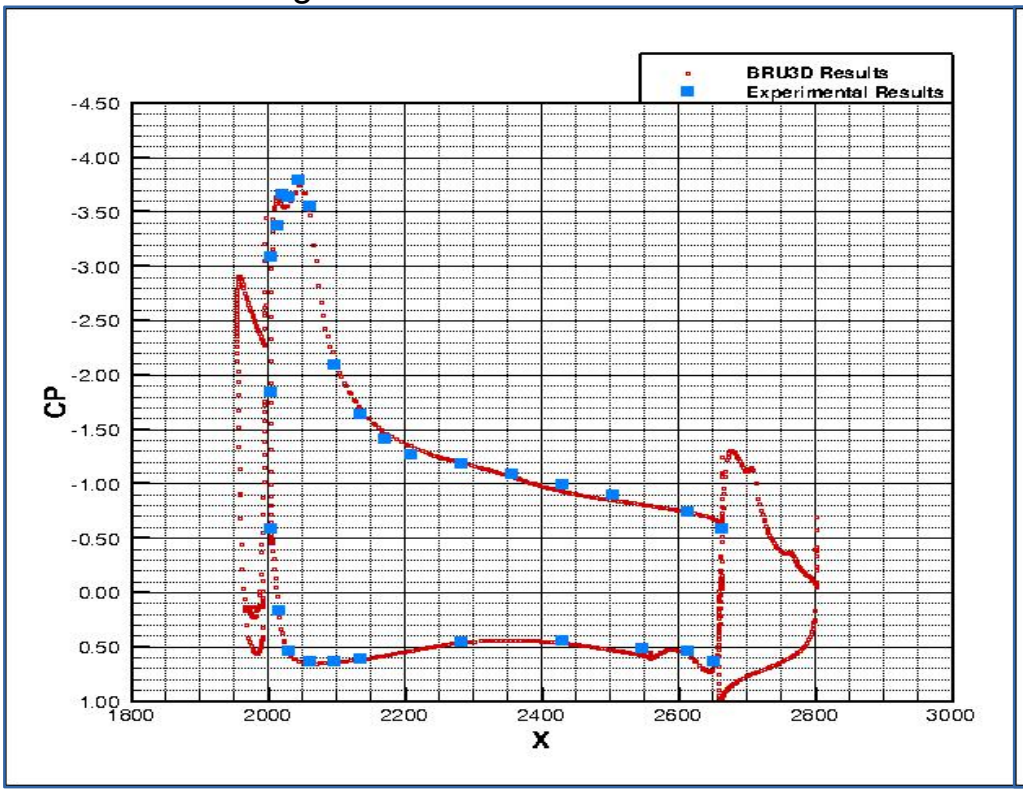
AOA = 10.47 deg



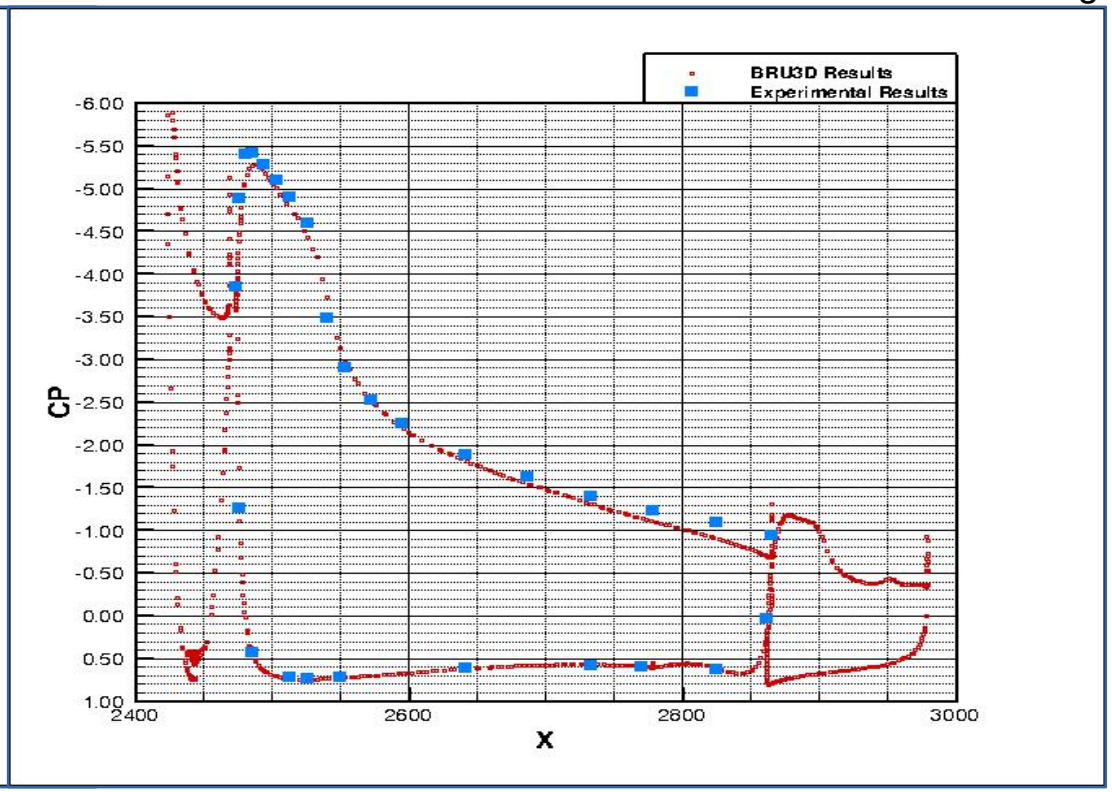
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – MAIN ELEMENT E - E

AOA = 14.54 deg



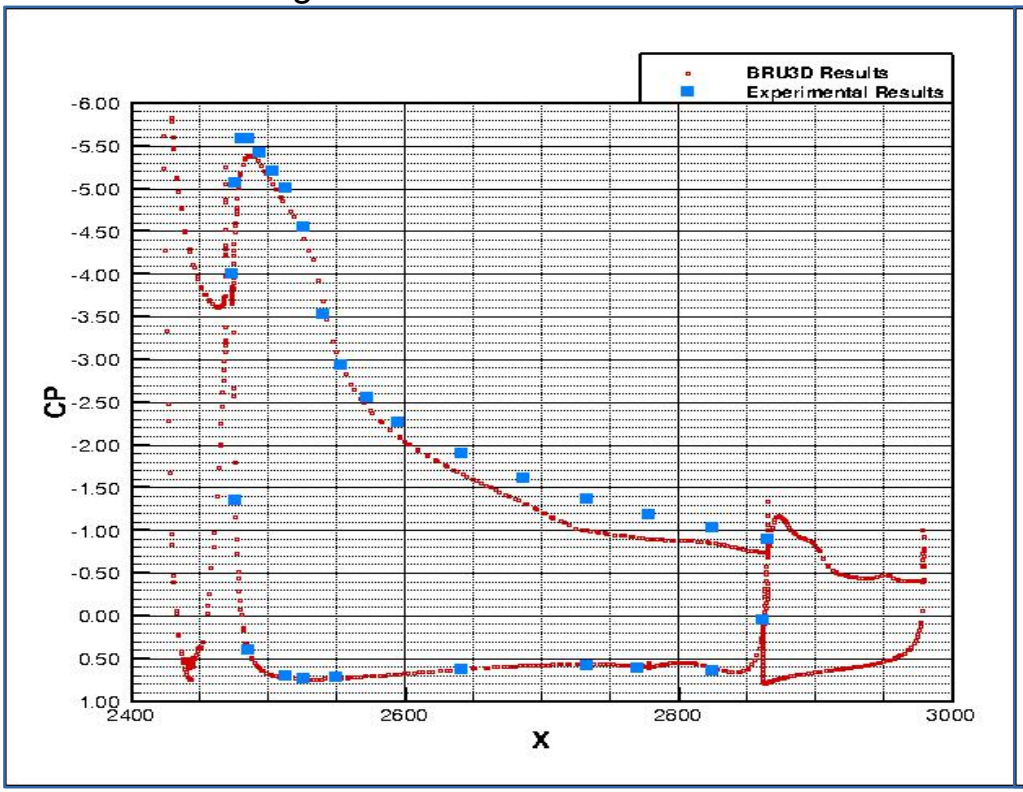
AOA = 18.58 deg



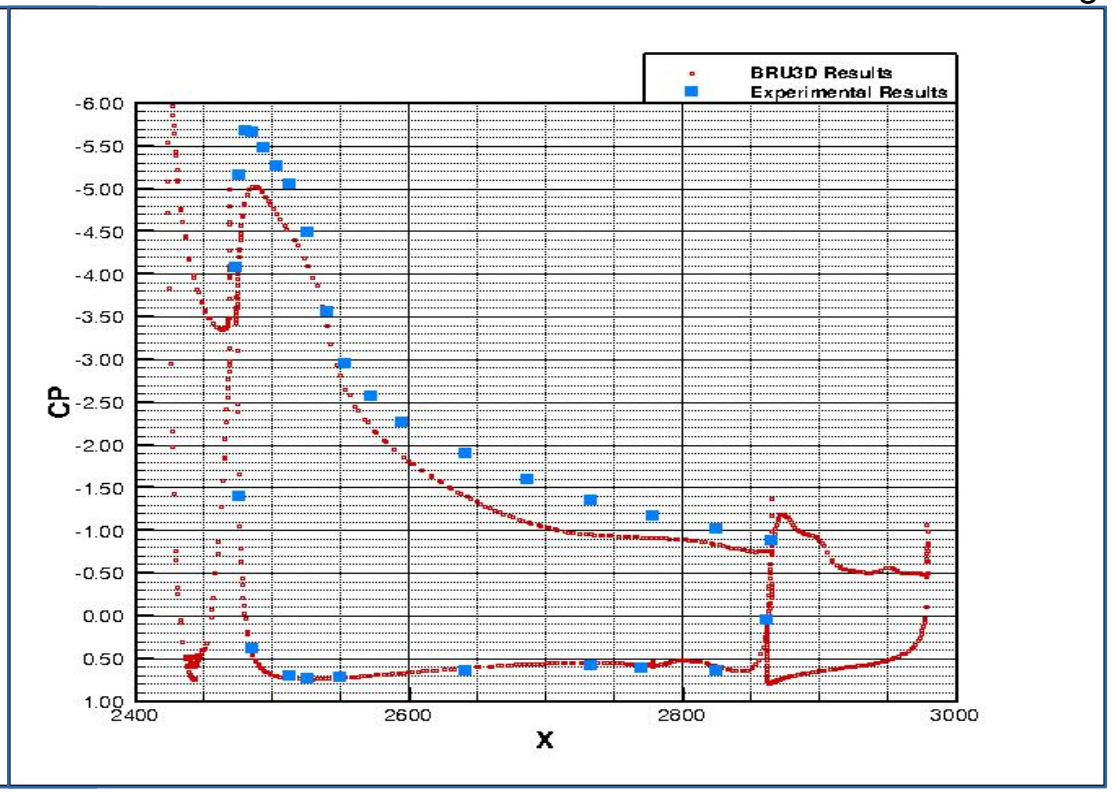
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – MAIN ELEMENT E - E

AOA = 20.57 deg



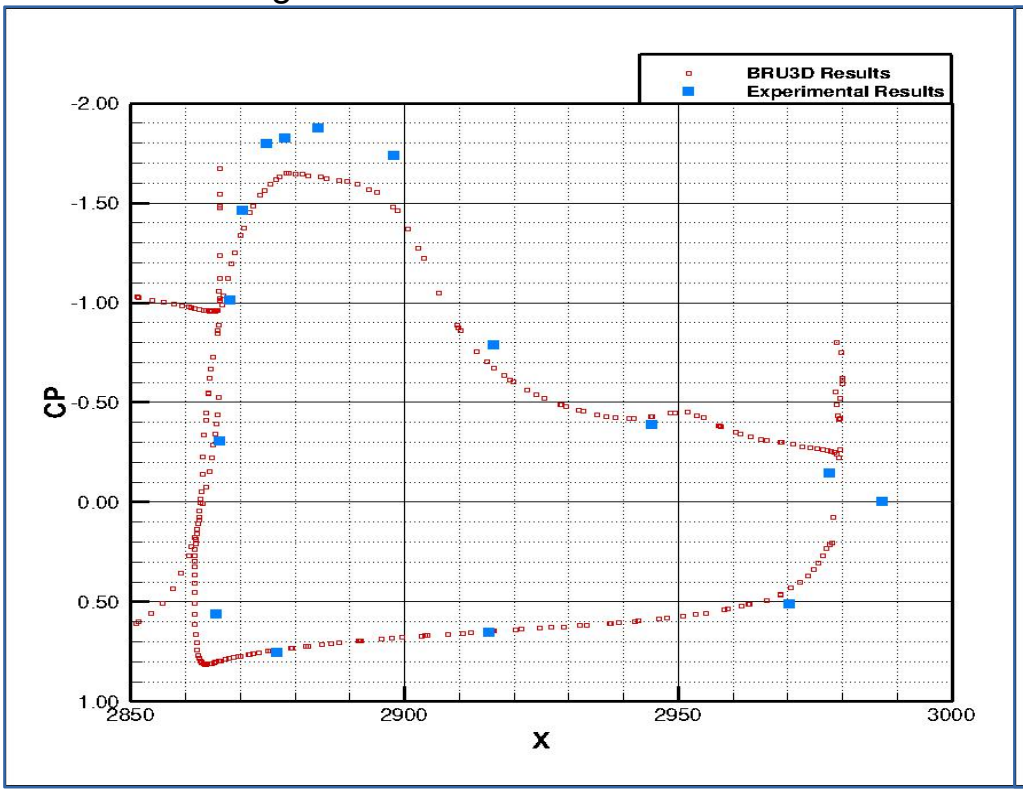
AOA = 21.59 deg



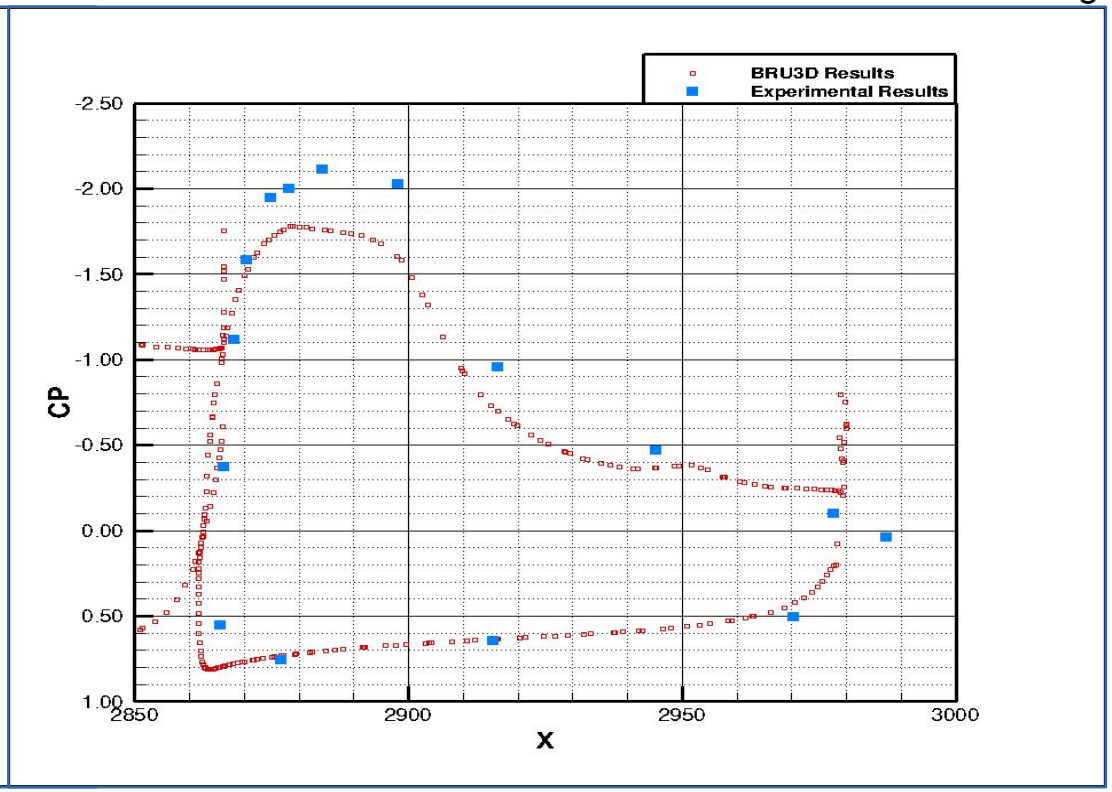
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – FLAP E - E

AOA = 4.36 deg



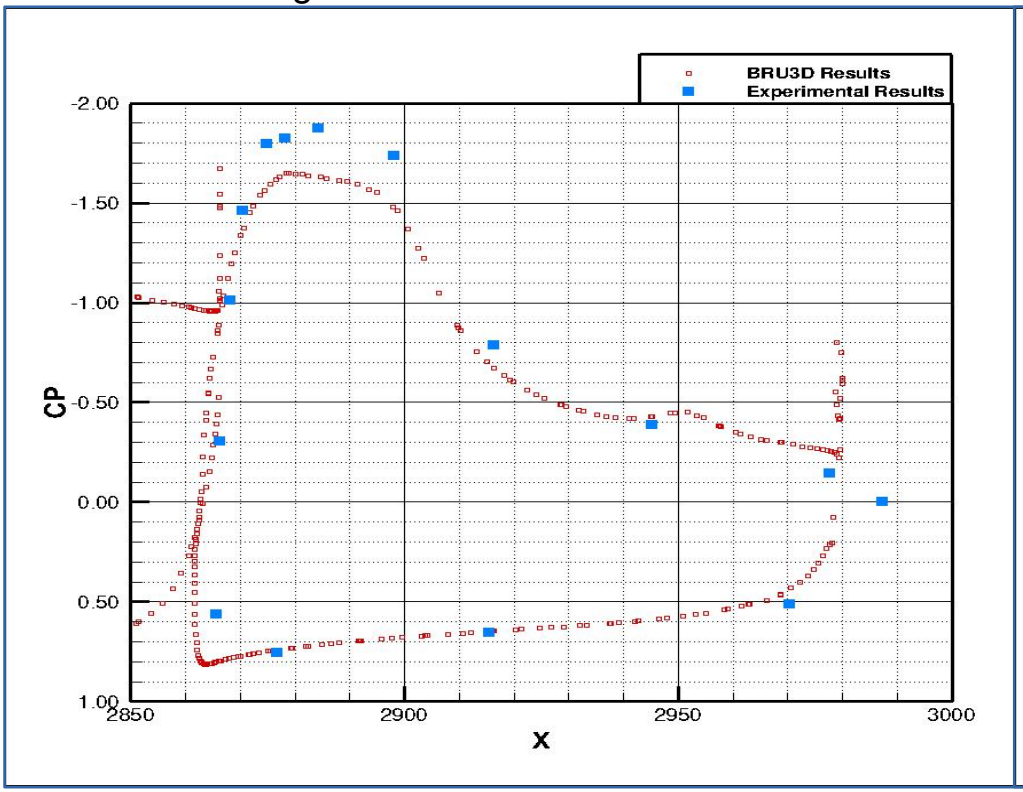
AOA = 10.47 deg



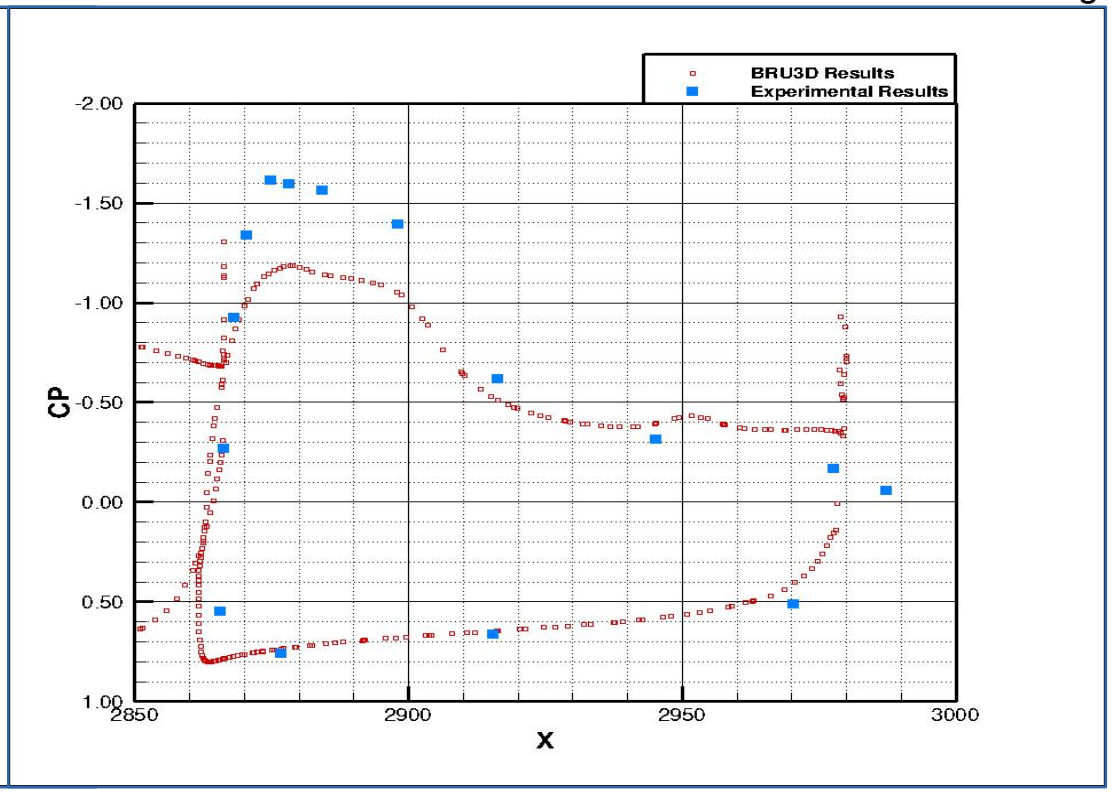
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – FLAP E - E

AOA = 14.54 deg



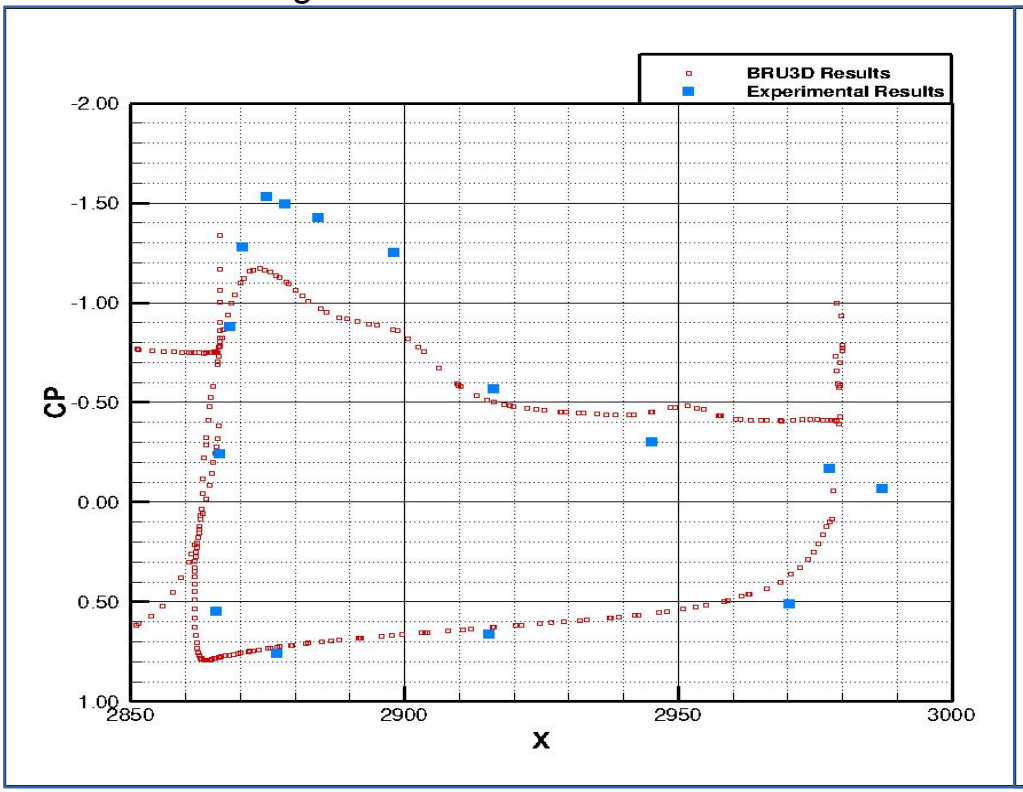
AOA = 18.58 deg



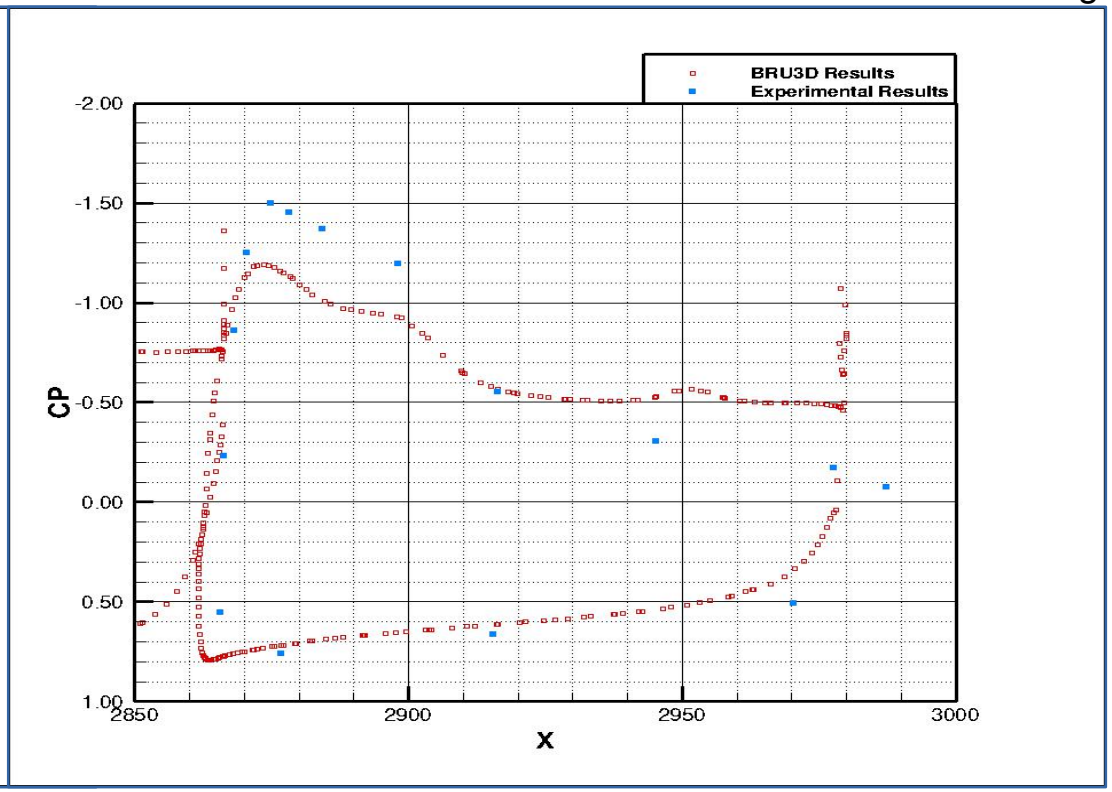
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – FLAP E - E

AOA = 20.57 deg

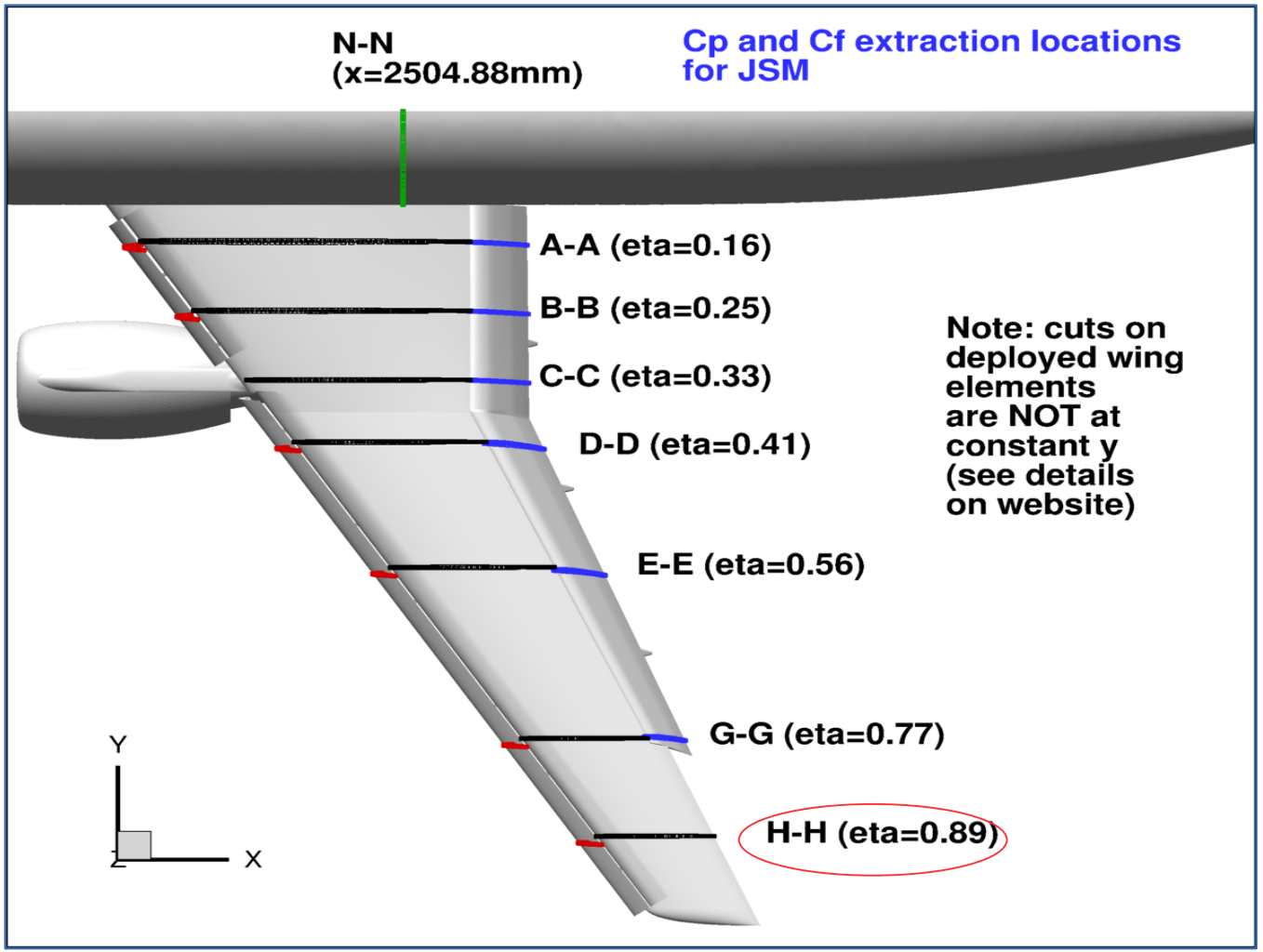


AOA = 21.59 deg



CASE 2c - WBPN
Comparison of CP distribution

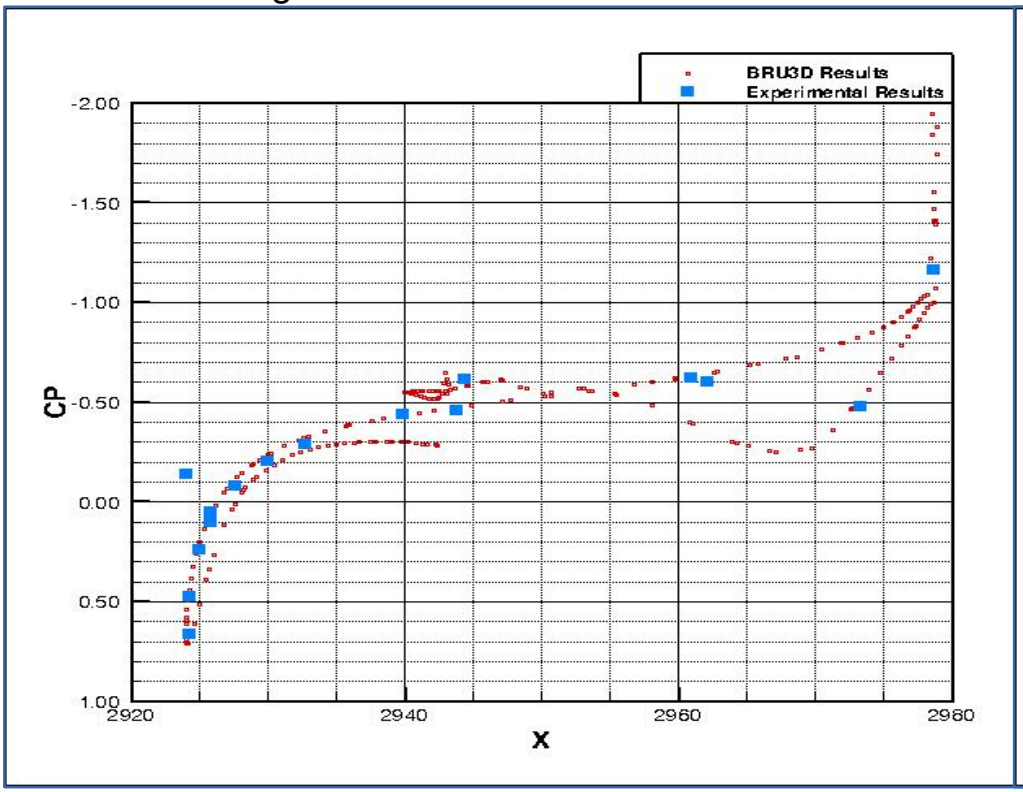
- Postprocessing: Surface Data Extraction for JSM (Case 2)



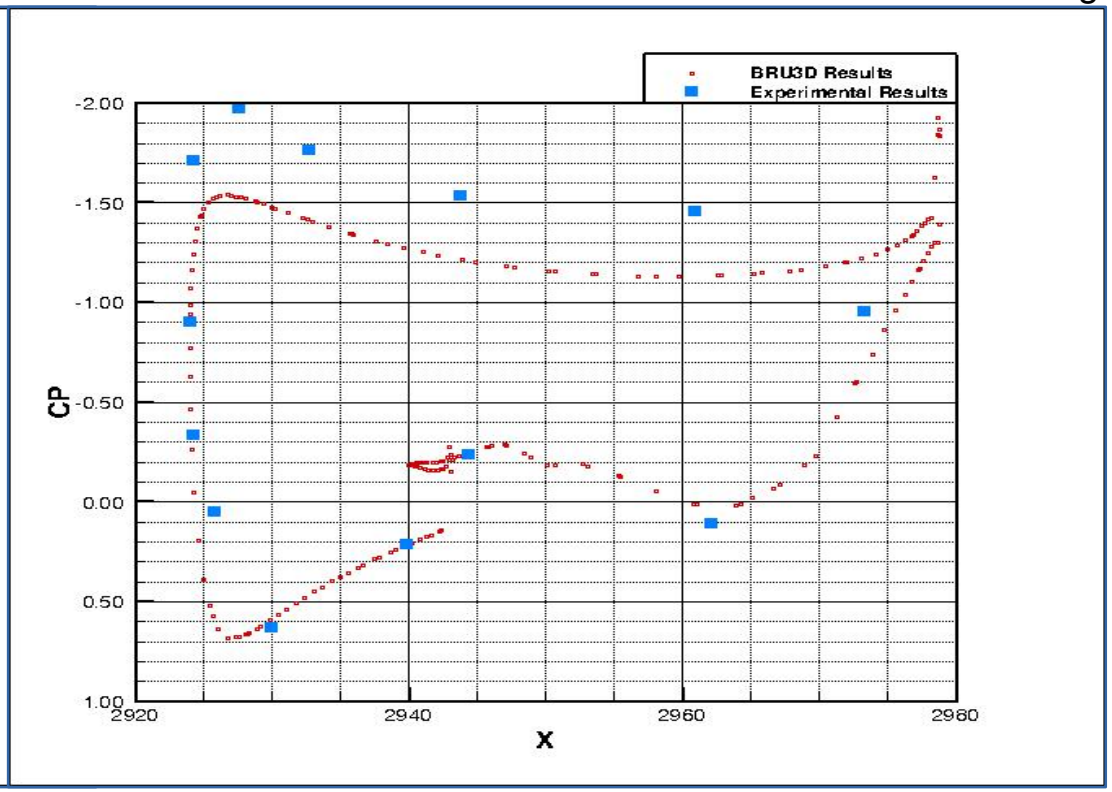
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – SLAT H - H

AOA = 4.36 deg



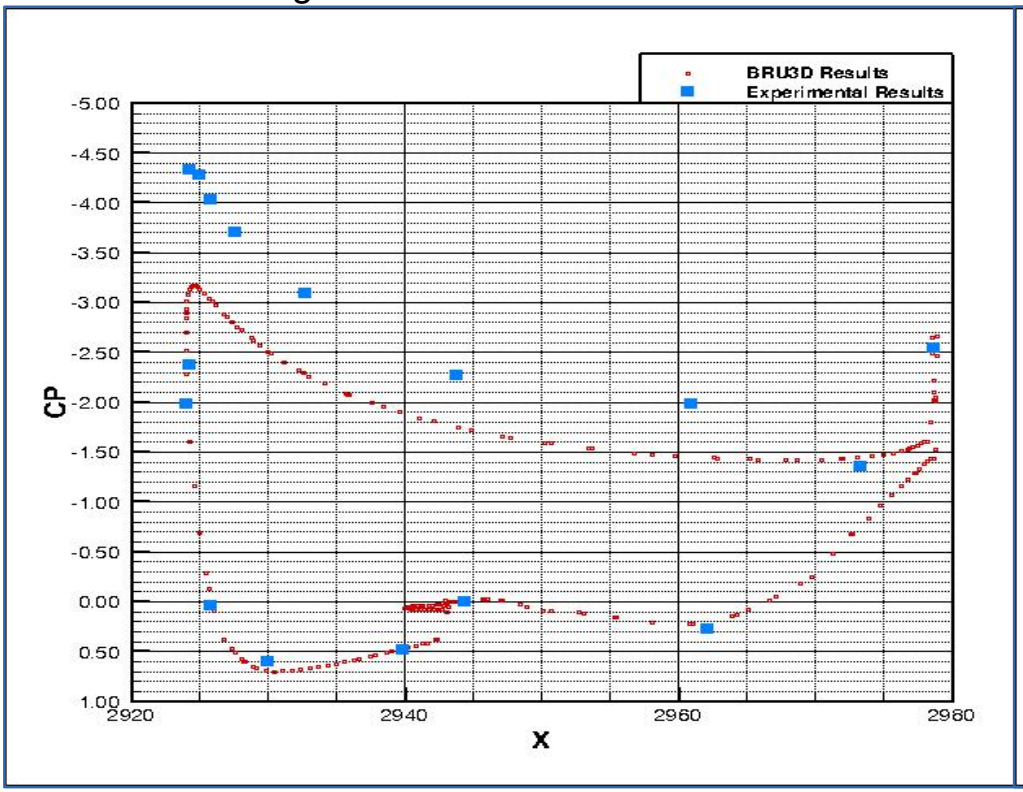
AOA = 10.47 deg



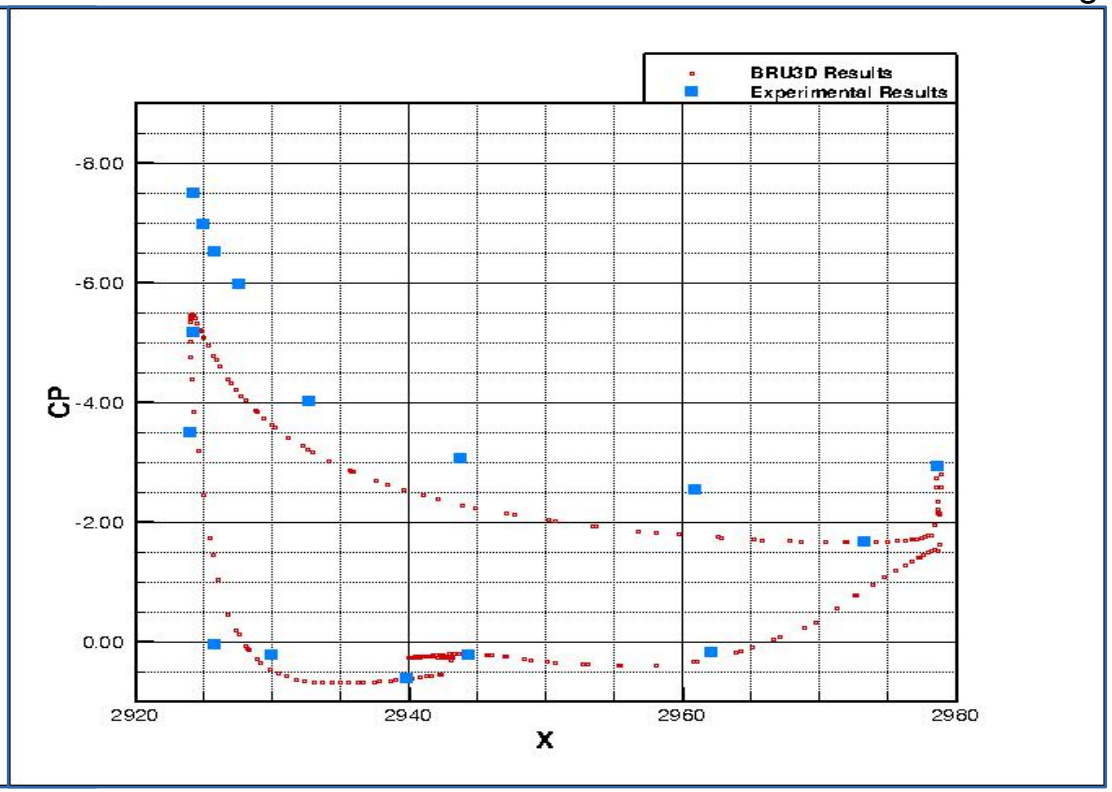
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – SLAT H - H

AOA = 14.54 deg



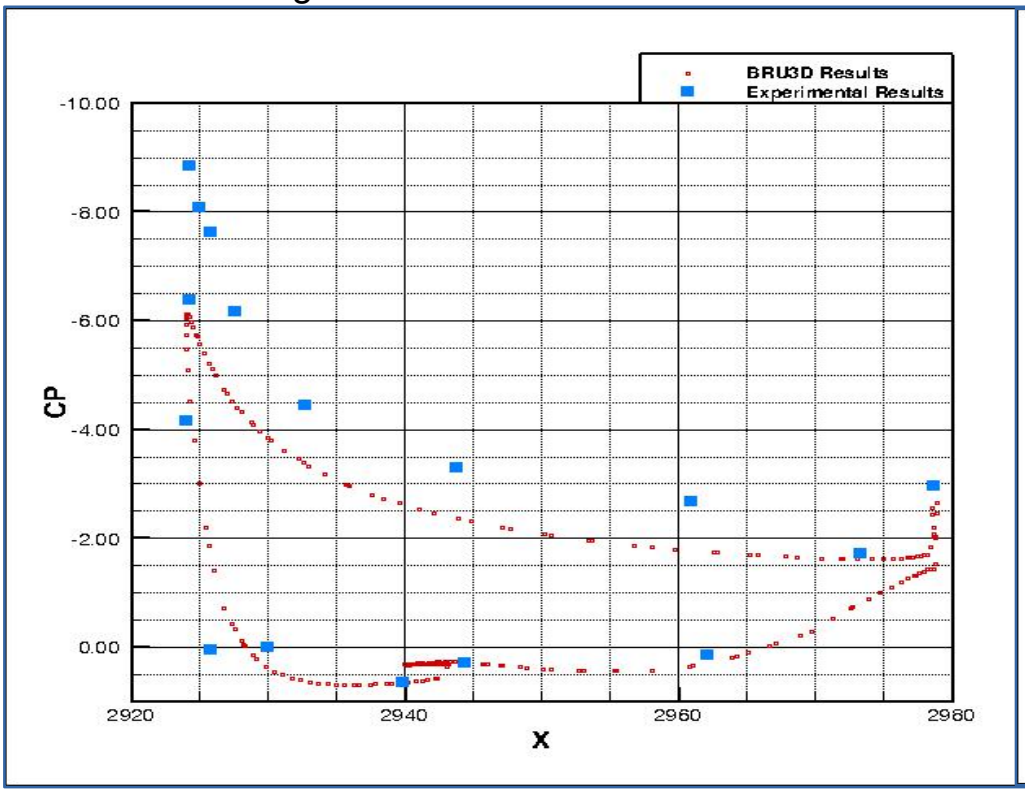
AOA = 18.58 deg



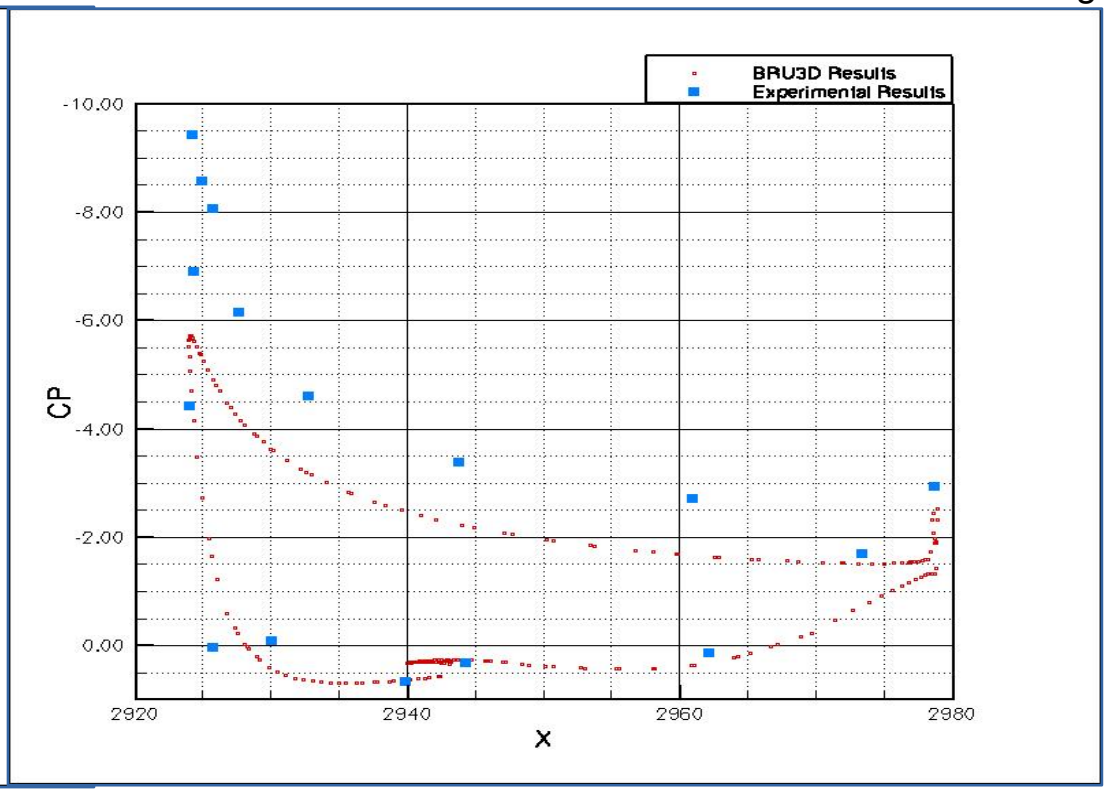
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – SLAT H – H

AOA = 20.57 deg



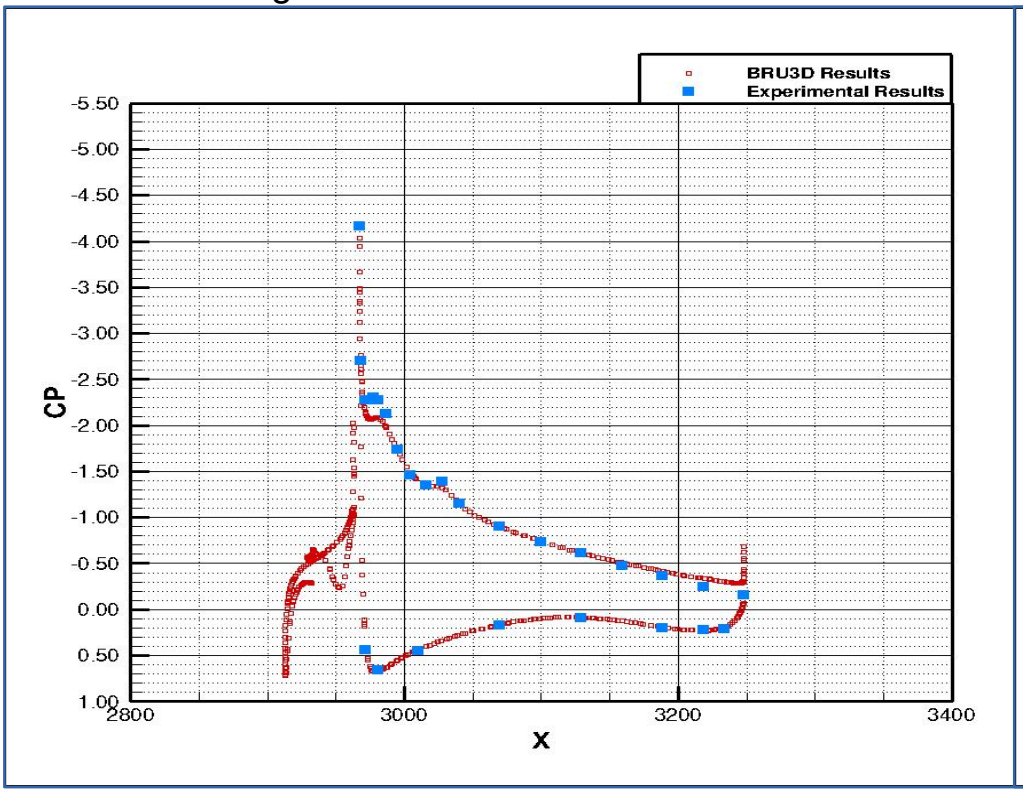
AOA = 21.59 deg



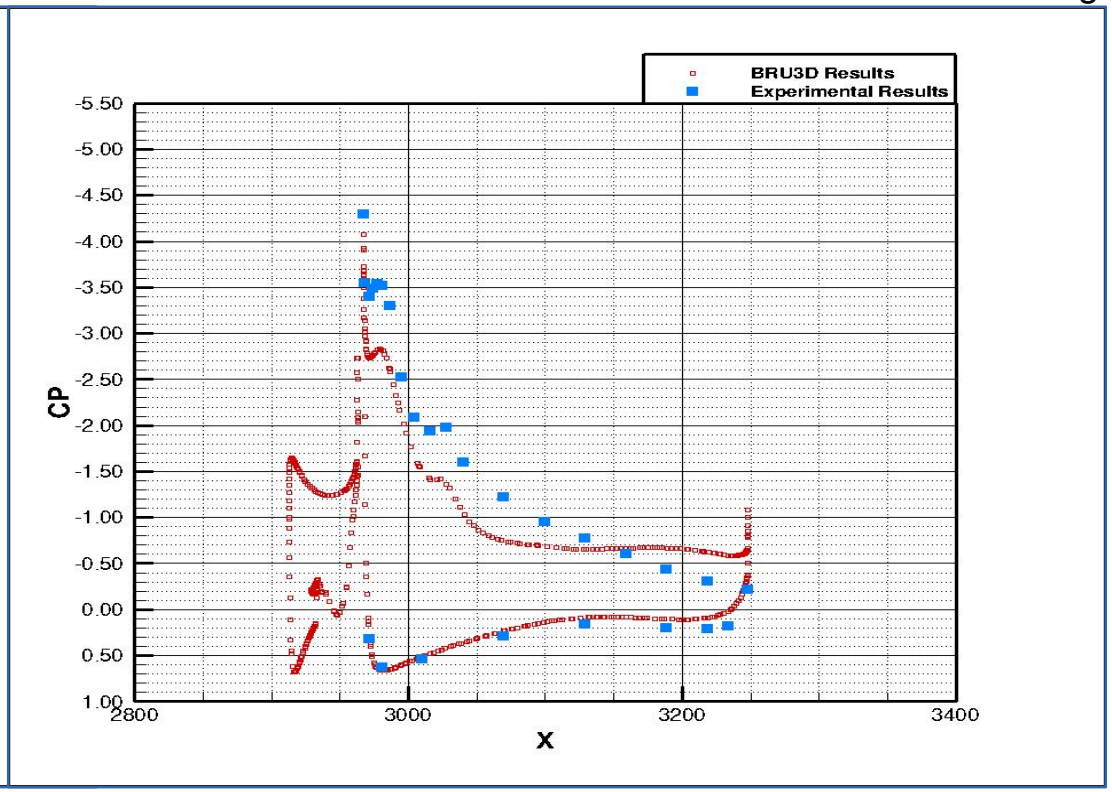
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – MAIN ELEMENT H – H

AOA = 4.36 deg



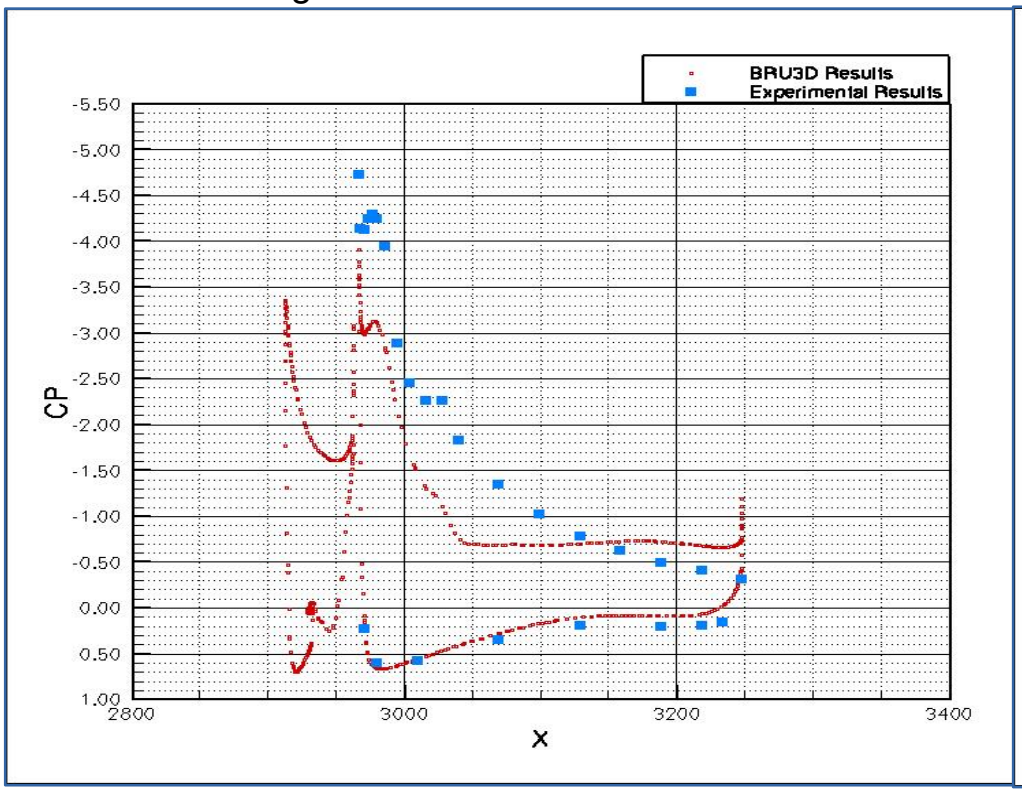
AOA = 10.47 deg



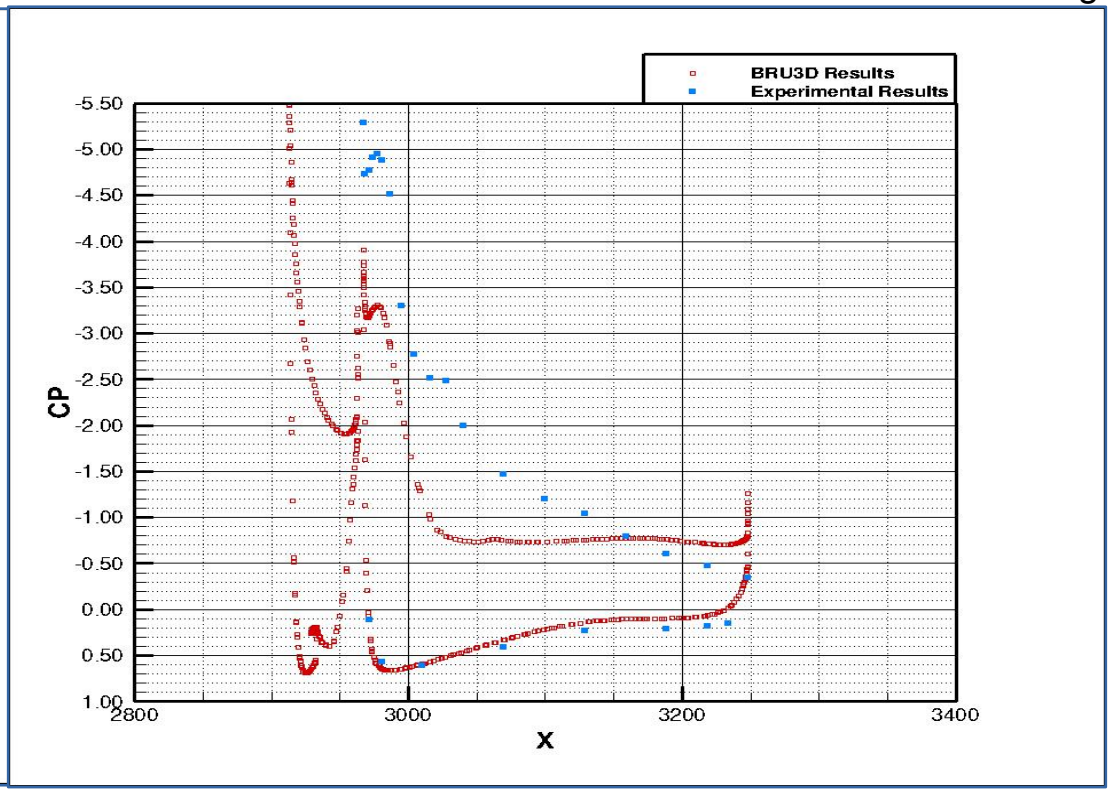
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – MAIN ELEMENT H – H

AOA = 14.54 deg



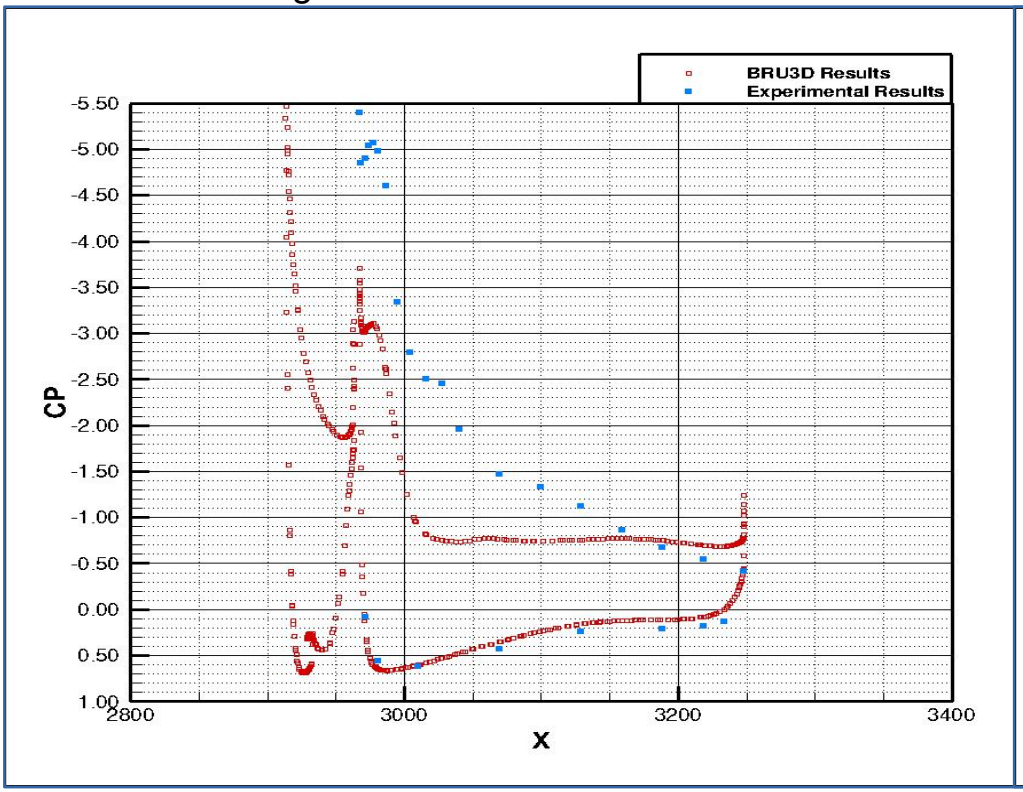
AOA = 18.58 deg



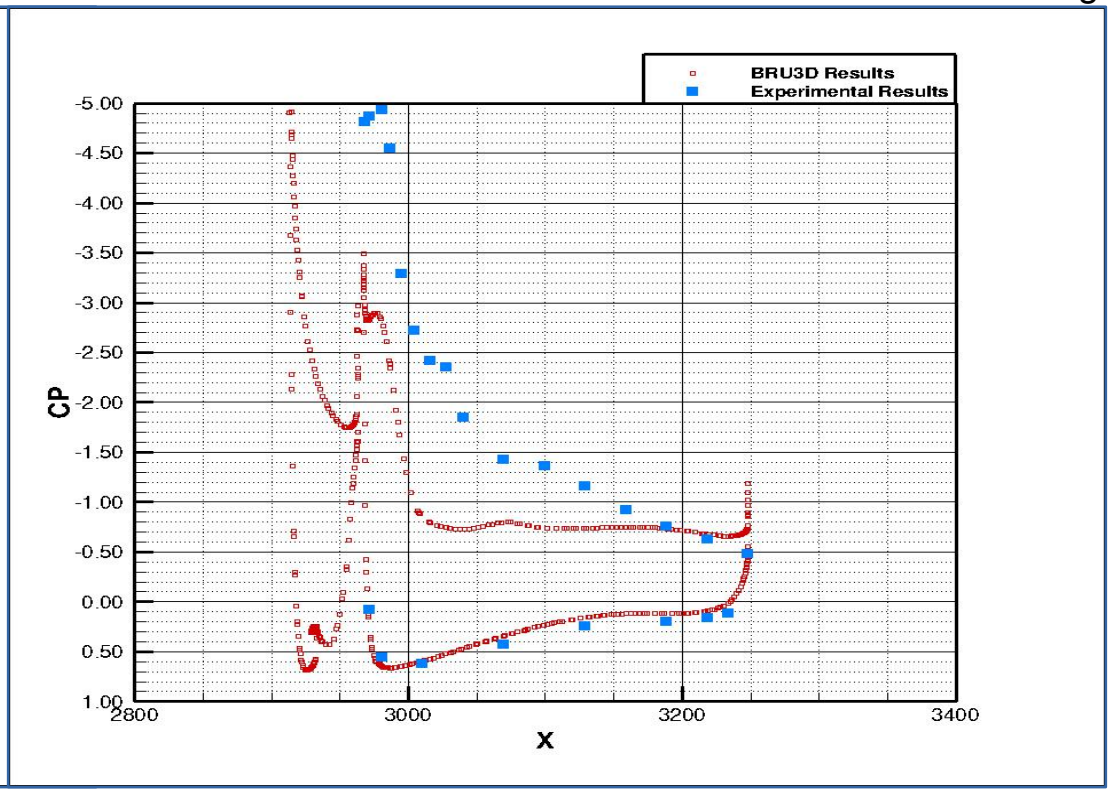
CASE 2c - WBPN
Comparison of CP distribution

- WBPN – MAIN ELEMENT H – H

AOA = 20.57 deg



AOA = 21.59 deg



Concluding Remarks

- **Case 1a**
  - The flow at inboard flap reattaches as the AOA increases from 8 to 16 deg.
  - On the other hand, the flow at outboard flap remains separated.
  - The largest variations in Cp distribution, as the mesh is refined, occur in the outboard flap and at the aileron region for AOA 16 deg.
  - The differences are related to flow separation.
  - The mesh refinement modifies the peak of minimum Cp along the main element.

Concluding Remarks

- Case 2a: WB configuration - Stall characteristics
  - Experimental results – Stall is triggered by the horseshoe vortex at the wing root.
  - Numerical results – Stall starts further outboard along the wing span.

- Case 2c: WBPN configuration – Stall characteristics
  - Experimental results and numerical results show stall as consequence of wing root horseshoe vortex and nacelle-wake separation on inboard wing panel.
  - These flow features prevent the growth of the wing load at the inboard wing panel region.

- For Cases 2a (WB) and 2c (WBPN), the comparison between experimental results and numerical results show a good agreement when the flow is attached.

Thank you !